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The drawing on the cover is of the barque Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

CONTENTS

Editorial:
Macromolecules 41

Antibodies and Specific Biological Forces 43
LINUS PAULING, B.S., M.A., Ph.D., D.Sc.

John Dalton 54
J. R. PARTINGTON, M.B.E., D.Sc.

The Polarization Microscope 57
B. K. JOHNSON, D.I.C.

Structural Inorganic Chemistry 66
WILLIAM WARDLAW, D.Sc., F.R.I.C.

Rocket Exploration 70
ARTHUR C. CLARKE

Plant Tissue Culture 75
R. J. GAUTHERET, D.Sc.

Book Reviews 80

Notes on Contributors *cover iii*

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ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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Macromolecules

Of all natural phenomena, life is the most enigmatic. 'The proper study of mankind is man' is an aphorism which the scientist might reasonably interpret within his own sphere as implying that the principal aim of science is the explanation of that complex of properties which distinguishes the quick from the dead. There are many approaches to the problem, but organic chemistry has hitherto proved the most successful. This is no doubt one of the reasons why it has never lacked a host of enthusiastic disciples: organic substances are so closely related to life and to fundamental human needs that they possess a fascination totally different from that of inorganic compounds.

A few decades ago, however, organic chemistry seemed to have reached an impasse in its revelation of the mechanism of life. A student of the subject could find satisfaction in the vast accumulated knowledge of the preceding hundred years, which had settled beyond doubt not only the constitution of such simple bodies as benzene, urea, acetic acid, alcohol, acetone, and so forth, but that of much more complicated substances, including several alkaloids, terpenes, and natural colouring matters. This satisfaction was, however, damped by the disappointing fact that many organic compounds of the greatest importance and interest—for example proteins, rubber, and starch—could be described only in general terms. The outlines of their structures were known but the details were obscure, and the possibility of synthesis seemed far distant. Thus in the field of protein chemistry successful attempts had been made to join together a few amino-acids to form simple polypeptides; but, valuable though the work was in confirming and extending our knowledge of proteins, only the most sanguine chemist could seriously believe that a mere extension of this process could lead to a satisfactory method of synthesizing proteins. The same problems were encountered in every other field of organic chemistry which involved the study of very large molecules; the available methods were inadequate either to disclose the full details of the structure, or to hold out any promise of synthesis even if the structure could be determined. It was clear that the science had temporarily overreached itself, and was entering regions for which it was not yet properly equipped.

The difficulty proved only temporary and, as has often happened in the past, fresh progress resulted not only from the applications of existing knowledge but from wholly new inspiration and improved techniques. The principal need was for more fruitful methods of elucidating the structure of large molecules and of synthesizing them. It was not long before the need was met. Outstanding among the new techniques is the method of X-ray analysis, which has proved of fundamental value in determining the nature of the repeating unit in long-chain molecules and, in its latest form, has proved capable of establishing the complete atomic configuration of very large but not polymerized molecules such as those of cholesterol and penicillin.

Another very valuable instrument for the investigation of large molecules is the ultracentrifuge, the development of which has been carried out chiefly by the team of investigators headed by The Svedberg, whose article on this subject was published in ENDEAVOUR in 1947. Yet another extremely fruitful method of analysis, especially for proteins, is the method of partition chromatography developed by A. J. P. Martin and his collaborators (ENDEAVOUR, January 1947). This has made practicable the quantitative analysis of proteins in Lilliputian quantities—far smaller than would have been considered necessary even five years ago. Application of the method has already yielded a great deal of information about the order

of amino-acid residues in a number of different proteins, together with other structural details, and it is evident that it has immense possibilities for investigating problems in this field.

Work on the synthesis of macromolecules has kept pace with that on their analysis. Forty years ago relatively little was known about the mechanism of polymerization and there was no market for artificial polymers. In most cases polymerization was regarded merely as a tiresome side reaction interfering with more important studies. Today the picture is entirely different. Greatly increased knowledge of the structure of natural polymers has advanced theoretical chemistry and at the same time has led to an increase in the number of practical applications of these substances. The manufacture of polymers has become an important branch of chemical industry, and many of the new products are important factors in our everyday life.

These noteworthy results have been achieved partly by the perfection of new analytical and synthetic processes and partly by the evolution of a new mental attitude towards the synthesis of large molecules. The impracticability of successively linking small units, such as sugars or amino-acids, to form very large molecules, the molecular weight of which may be measured in tens of thousands, has been recognized. Instead, attention has been focused on ways of making simple substances polymerize smoothly and rapidly without the occurrence of unwanted side reactions. Artificial rubber, Perspex, polythene, and silicone resins are but a few among scores of polymers which have been developed during the last few years.

It remains to be seen to what extent the controlled polymerization of simple substances, or of mixtures of simple substances, can be used for the exact synthesis of natural polymers such as proteins. We know that although many natural polymers may consist of relatively few different kinds of unit—a dozen different amino-acids, for example—the order and frequency in which these occur may be very complex. To achieve precisely the same order and frequency by direct polymerization of the simple units would need more delicate control than can yet be achieved. At present, the most that can be done is to synthesize polymers which possess the same general atomic configuration, and consequently the same kind of properties, as natural polymers. It may well be that the precise duplication of natural polymers in the laboratory must await the development of methods as yet unknown.

The main article in this issue is by Professor Linus Pauling, who discusses antibodies and specific biological forces—a field in which his own contributions are well known. This article both illustrates the extent of our knowledge of macromolecules and shows how closely connected are branches of science which only a few years ago appeared to be diverging rather than converging. The quantum theory, advanced originally to explain certain peculiarities of black-body radiation, proved invaluable in elucidating the nature of the chemical bond. An understanding of the forces which bind atoms and molecules together encourages the hope that it will eventually be possible to express the phenomena of life in terms of the molecular structure of the organism. Few problems are of more contemporary importance in science, and none is of greater practical importance in medicine, than an understanding of the relationship between antibody and antigen. That it is now at length possible to discuss this relationship in terms of established scientific theory is a measure of the speed with which the study of macromolecules has advanced during recent years. Another milestone has been reached on the road to the elucidation of life, through inventive skill and 'profound thought, the fine balance of truth in observing, with the imaginative faculty in modifying, the objects observed.'

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Antibodies and specific biological forces

LINUS PAULING

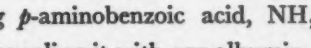
Advances in organic chemistry during the past century have made it possible to identify the structure of many of the simple substances found in living cells and to understand such chemical changes as respiration and excretion. Only recently, however, have there seemed sure grounds for believing that knowledge and technique have advanced far enough to permit an eventual elucidation of such highly complex problems as the relationship between antibody and antigen, and other fundamental phenomena of life.

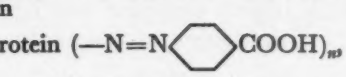
Significant progress has recently been made in the attack on the problem of the nature of specific biological forces, and also on the related problem of the mechanism of manufacture of complex biological molecules with specific properties. For example, animals are able to synthesize various proteins fulfilling special functions—such as haemoglobin, which carries oxygen from the lungs to the tissues. The molecule of haemoglobin is large and complex. It contains about 10,000 atoms, and its molecular weight is 68,000. It has the property of combining reversibly with oxygen, and will react to the presence of carbon dioxide by tending to liberate the combined oxygen. The properties of haemoglobin are not exactly the same for animals of different species, but vary from species to species. The variation is sometimes of such a nature as to be obviously useful to the animal—thus the haemoglobin of cold-water fishes liberates its oxygen at lower temperatures than does that of warm-blooded animals.

The problem of the way in which an animal is able to manufacture the special molecule of haemoglobin that it needs is part of the general problem of the manufacture of specific biological substances. For example, a virus molecule in the proper environment (that provided by its host) is able to cause the production of replicas of itself, and the phenomena of heredity depend upon the similar autocatalytic action of molecules of genes present in the chromosomes and also in the cytoplasm of cells.

The specificity shown by the synthesizing system in cells in manufacturing haemoglobin molecules of a particular type, or other complex substances with specific biological properties, is observed in many other phenomena. Plants and animals form enzymes which have the special powers of catalysing certain chemical reactions, such as the hydrolysis of a polypeptide chain at the link between two definite amino-acid residues or the successive stages in the oxidation of foods. A striking example of specificity in properties is shown by antibodies, substances produced by an animal after the injection of a foreign material, the antigen. In general, antibodies produced in response to the injection of a particular antigen have the power of combination with the homologous antigen used in their production, but not with other substances, except those that are very closely related in molecular structure. Thus the problem of the structure of antibodies, in relation to their power of specific combination with the homologous antigen and to the mechanism of their production, bears on both of the basic problems of biology mentioned above.

The work of Karl Landsteiner contributed greatly to the development of the present understanding of the nature of serological reactions. After he had discovered the human blood-groups, Landsteiner began a penetrating series of experimental studies, designed to throw light on the problem of the nature of serological reactions. Most important was his discovery that it is possible to cause an animal to manufacture antibodies with the power of specific combination with various chemical groups of known structure. Beginning in 1917, he and his collaborators prepared artificially conjugated antigens by coupling relatively simple chemical substances to proteins, and then injecting these artificial antigens (usually azoproteins, with structure protein—N=N—R, made by coupling a diazotized amine to the protein molecule) into animals. Landsteiner thus produced antisera which were found to contain antibodies with the power of combining with the protein used in manufacturing the azoprotein, and also antibodies with the specific power of combining with the attached group of known structure, which he called the haptenic group. The most useful method for studying the combining power between antibodies and homologous

antigens is the precipitation method—an antiserum mixed in proper proportions with a solution of the homologous antigen forms a precipitate with it, whereas it is not able, in general, to form a precipitate with other substances. For example, Landsteiner prepared an azoprotein by diazotizing *p*-aminobenzoic acid,  , and coupling it with egg albumin, to produce the azoprotein



containing several haptenic groups attached to each molecule of protein. He found that the antiserum made by injecting a rabbit with this azoprotein not only had the power of forming a precipitate with a solution of the original azoprotein, made from egg albumin, but could form a precipitate with a solution of an azoprotein made with any other protein, such as bovine serum albumin, by coupling it with diazotized *p*-aminobenzoic acid. This property of precipitation with any azoprotein containing the *p*-aminobenzoate ion group shows that the antibody has developed the power of combining with this haptenic group. The combining power is, moreover, highly (but not completely) specific. The antiserum does not form a precipitate with an azoprotein made by coupling some unrelated substance, such as diazotized *p*-aminosuccinanilic acid, with a protein, but has the power of forming a small amount of precipitate with azoproteins made with closely related substances, such as a substituted *p*-aminobenzoic acid with a group or atom such as methyl or chlorine also attached to the benzene ring. The picture of the structure of antibodies described below had its origin in large part in an attempt to interpret the nature of the serological cross-reactions observed by Landsteiner in terms of the molecular structure of the haptenic groups. Landsteiner's work is summarized in his book *The Specificity of Serological Reactions*, the first edition of which was published in 1936 and the second edition (after his death) in 1945 [1].

The following picture of the process of formation of antibodies under the influence of a molecule of antigen was developed during a vigorous effort to imagine the simplest structure that could be suggested, on the basis of the information available about intramolecular and intermolecular forces, for a molecule with the properties observed for antibodies, and also to imagine the simplest reasonable process of formation of such a molecule [2]. This theory of the structure and process of formation of antibodies is based upon the concepts that the forces between an antibody and its homologous antigen are the ordinary short-range forces known to exist between simpler molecules, and that the great specificity results from a detailed 'complementariness' in configuration extending over a considerable surface of the antigen molecule and the corresponding combining region of the antibody molecule. The concept of specificity of serological reactions as resulting from complementariness in structure was originally suggested by Breinl and Haurowitz [3], and was then independently presented by Jerome Alexander [4] and Stuart Mudd [5]. There is some intimation of it in the early work of Ehrlich (the lock-and-key theory), and of Bordet. The concept of the multivalency of antibody molecules and antigen molecules, now incorporated in the theory, is due to J. R. Marrack [6], and support for it was provided by the work of Michael Heidelberger. Many experimental studies carried out at Pasadena since 1940 have provided evidence in favour of the concept of complementariness and also of the multivalency of antibodies.

Let us describe the immediate precursor of a molecule of normal γ-globulin as a polypeptide chain, containing a thousand or more amino-acid residues arranged in a sequence determined by the nature of the system of enzymes and reticular structures constituting the cell in which the γ-globulin is being synthesized. We assume that this polypeptide chain can become either a molecule of normal γ-globulin or a molecule of antibody with specific combining power for an arbitrary antigen, according to the way in which the long and complex polypeptide chain is folded. It seems likely that some native proteins are of such a nature—i.e. have such a sequence of amino-acid residues—that of the many ways in which the chain can be folded one is characterized by being specially stable. This specially stable configuration might be that of the native protein; it is known that certain proteins, such as trypsin and haemoglobin, can lose their specific properties under the action of a denaturing agent, and can then regain them, presumably by re-coiling to the normal, stable configuration as the denaturing agent is slowly removed. However, we assume that the polypeptide chain of γ-globulin is of such a nature that a very great number of alternate ways of coiling the polypeptide chain have nearly equal stabilities. When the polypeptide chain is synthesized in the cell, in the absence of any foreign molecules the chain will tend to coil

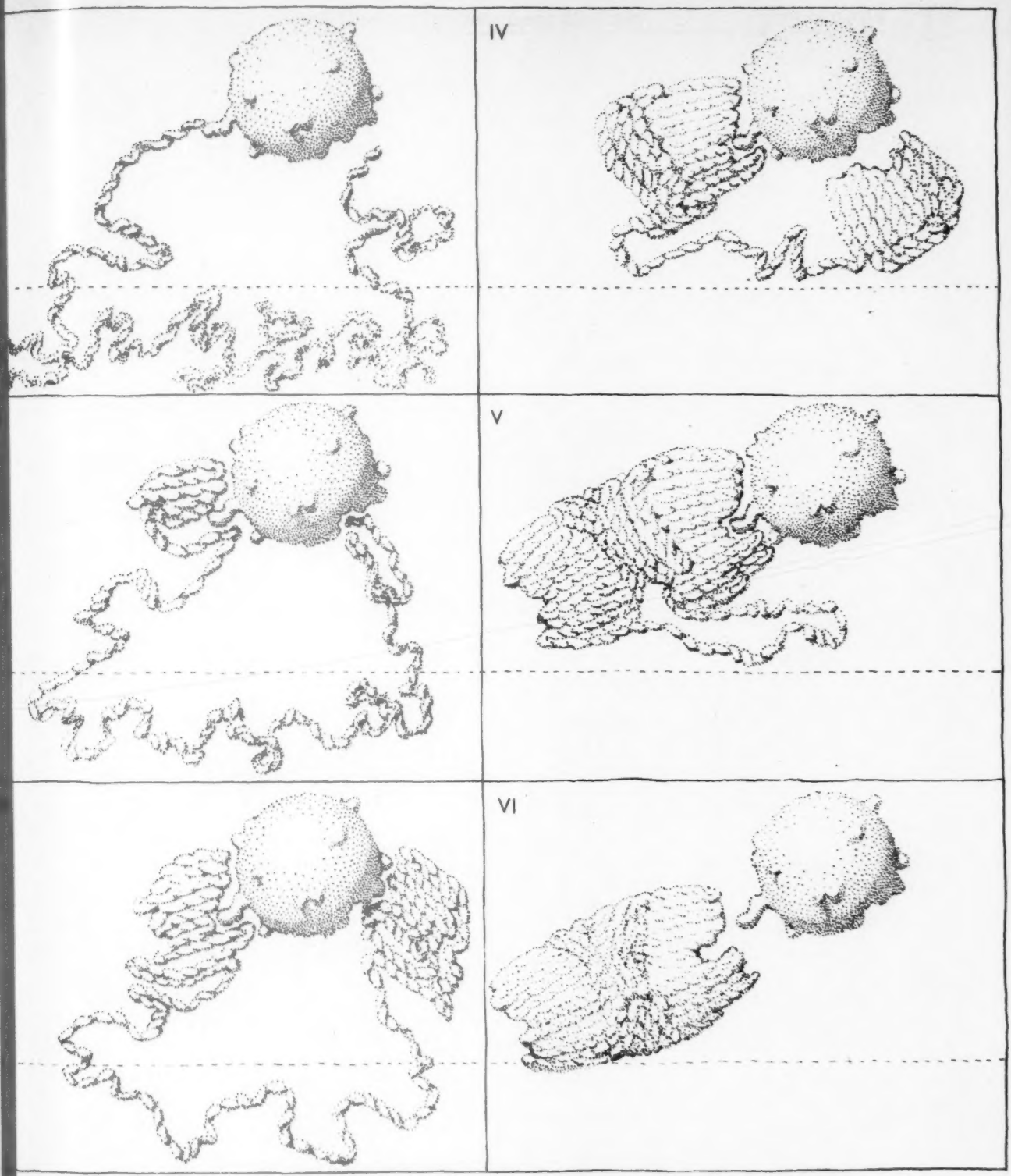


FIGURE 1 – *A postulated process of formation of antibody molecules. The polypeptide chain of the antibody precursor is folded, in the presence of an antigen molecule, into configurations complementary to the antigen.* (*See page* 49.)

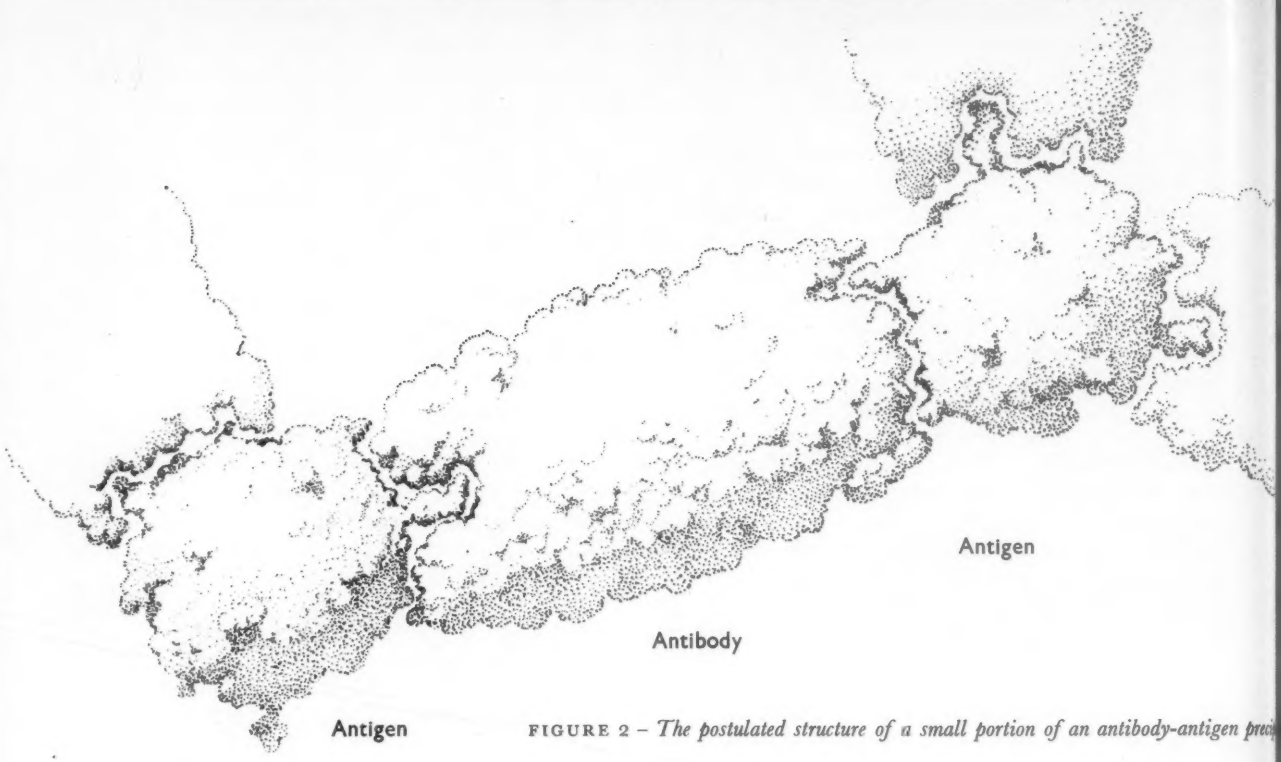


FIGURE 2 – *The postulated structure of a small portion of an antibody-antigen pre*

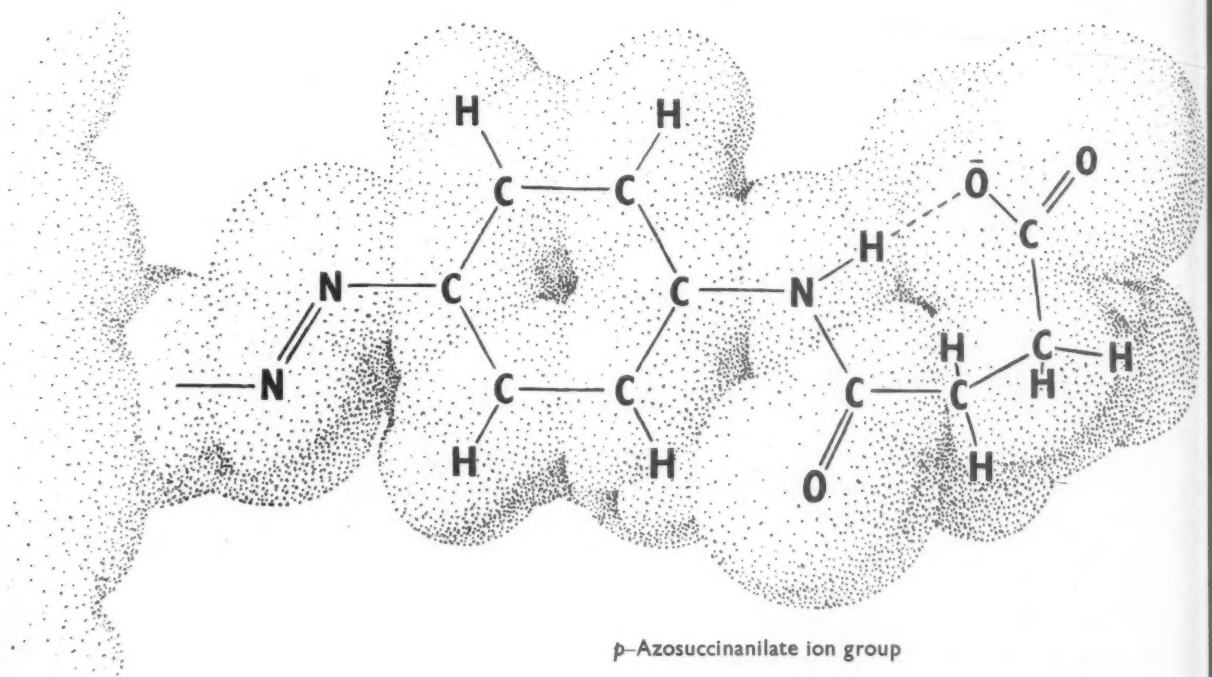


FIGURE 3 – *The structure of the haptenic group of an azoprotein, ovalbumin-*p*-azosuccinanilate ion.*

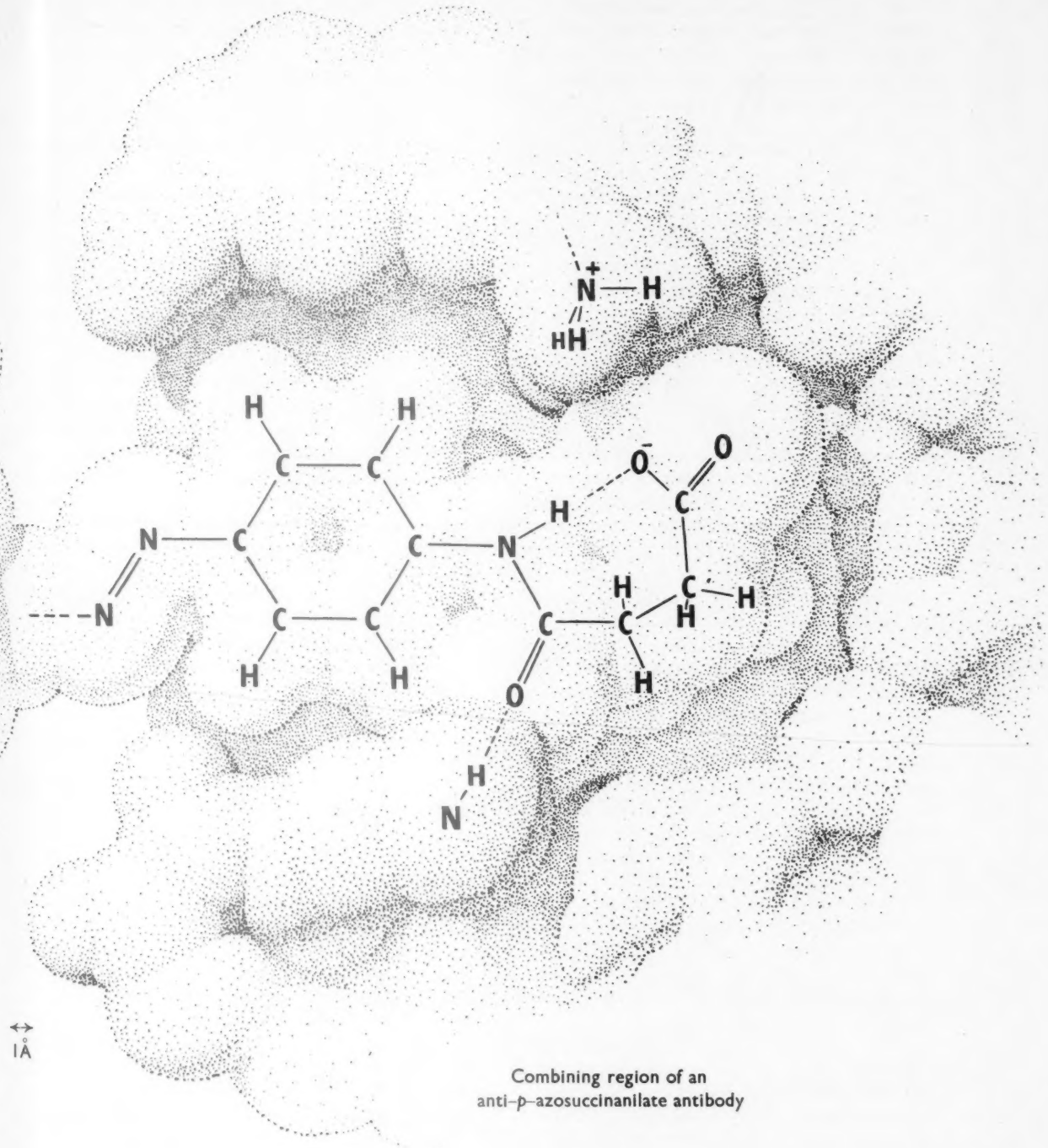


FIGURE 4 – *A haptenic group and a complementary region of its specific antibody.*

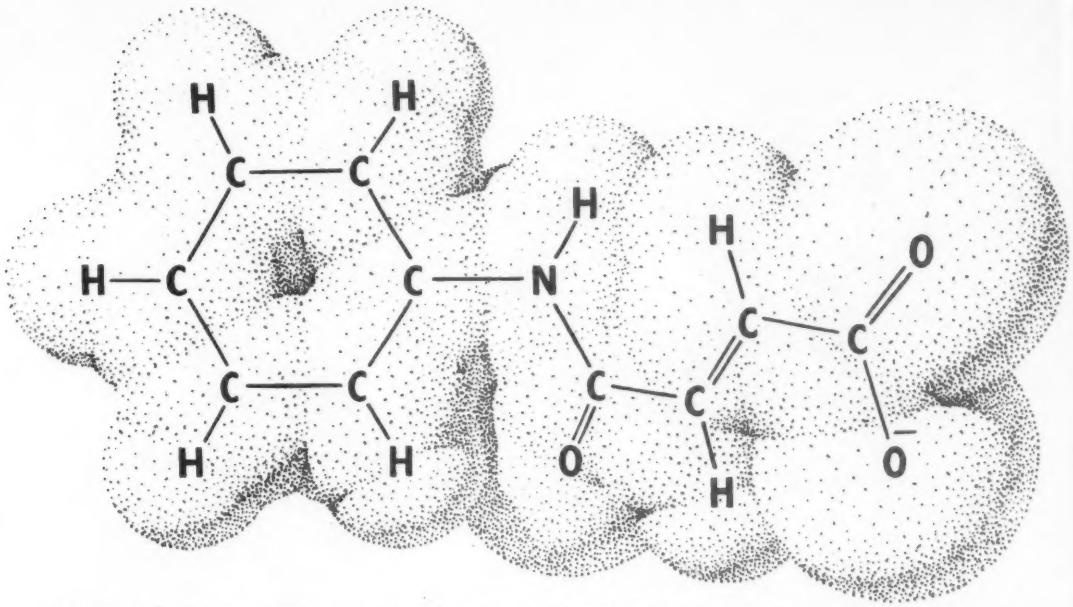


FIGURE 5 – *The fumaranilate ion, which has very small combining power with the antibody shown in figure* 4.

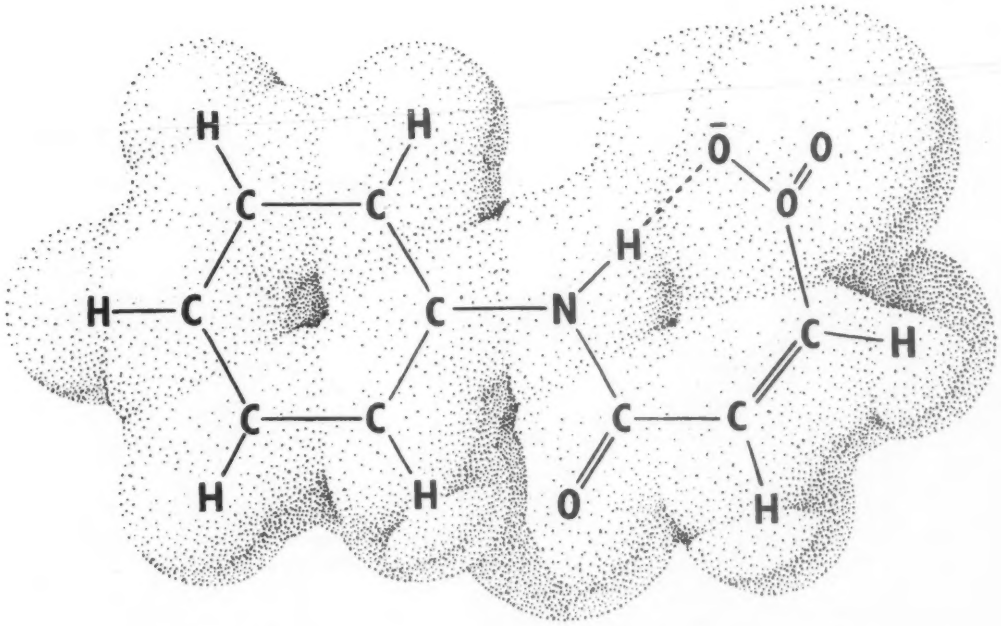


FIGURE 6 – *The maleanilate ion, which combines strongly with the antibody shown in figure* 4.

into that configuration which is most stable under the normal circumstances within the cell, producing a molecule of normal γ-globulin. If, however, there is present in the cell a foreign molecule, a molecule of antigen, the environment in which the γ-globulin polypeptide chain finds itself is different, and the difference in environment will be such as to stabilize others of the configurations accessible to the polypeptide chain, namely those which have the greatest power of attraction for the antigen molecule. This hypothetical process provides an automatic method by which a molecule is produced that is complementary in structure to a portion of the surface of an antigen molecule. The phenomenon is the same as the production of a coin by a die, or in general of a replica by the process of pressing a plastic material against a mould and permitting it to harden. The polypeptide chain, with its power of assuming alternative configurations, is the plastic material, and the surface of the antigen serves as the die or mould. The process of hardening is the result of the operation of the weak forces between different portions of the polypeptide chain that find themselves in juxtaposition; these weak forces, which individually could not withstand the disrupting effect of thermal agitation, co-operate, after the very large protein molecule has assumed its final configuration, to hold the molecule in that configuration.

In figure 1 the antigen molecule is represented as a roughly spherical aggregate of atoms, with a surface structure shown by protuberances and hollows. One of these protuberances might represent, for example, a *p*-azobenzoate ion haptenic group. The precursor of γ-globulin is shown as being synthesized in a region of the cell separate from that occupied by the antigen (this region being indicated by the line of dashes). In the first section of figure 1 two ends of a polypeptide chain are shown as liberated first from this region, and permitted to fold into the most stable of the configurations accessible to them. The ends of these two polypeptide chains are seen in the second section of the figure to be attracted to the surface of the antigen, and to assume configurations that make the forces of attraction between them and the molecule of antigen as great as possible. Inasmuch as most of the forces that are effective between molecules fall off very rapidly with increasing distance, and are strong only over a range of a few Ångström units, the stabilized configurations of the end of the polypeptide chain will be those that bring as large a portion as possible of each chain-end into immediate juxtaposition with a surface of the antigen molecule; that is, the structures of the combining regions will have as great a complementariness as possible with the surface structure of the antigen molecule. This complementariness includes not only the similarity in the surface configuration but the juxtaposition of special combining groups, such as a negatively charged group in the antibody with a positively charged group in the antigen, and a hydrogen-bond-forming group carrying the proton with a similar group presenting an electron pair.

The third section of figure 1 shows the antigen with two combining regions of the antibody formed. The central section of the polypeptide chain has not yet been folded. In the fourth drawing one of the combining regions of the antibody is represented as breaking away from the antigen, under the influence of thermal agitation; the central section of the polypeptide chain then folds into its stable configuration, fastening the two combining regions of the antibody together into the completed antibody molecule. In the fifth drawing this molecule is shown still attached to the antigen by one of its combining groups; in the sixth drawing the completed antibody molecule is represented as breaking away from the antigen under the influence of thermal agitation, forming a free antibody which may build up the antibody titre of the blood-plasma.

The assumption that most antibody molecules have two regions able to combine with antigen (i.e. are bivalent) accounts for some of the properties of antisera. For example, antibodies homologous to cellular antigens, such as red blood-cells, are able to cause these cells to agglutinate. The serum from humans with blood of type B or O contains antibodies capable of combining with the A antigen, which is present on human red blood-cells of types A or AB. When this serum is added to a suspension of these cells, the red cells clump together. The simplest explanation of this clumping is that an antibody molecule uses one of its combining groups to attach itself to the outer surface of one red blood-cell by combining with the A haptenic group present on this cell wall, and that then, on collision with another red blood-cell, it uses its other combining region to form a bond with the second cell, thus holding the two cells together. This process may continue until all of the cells are agglutinated into clumps. A similar explanation leads immediately to an understanding of the phenomenon of serological precipitation, as was pointed out by Marrack. The antigen

molecule may use various portions of its surface to attach itself to several antibody molecules, as indicated in figure 2, and each of these antibody molecules may then use its second combining group to bind further molecules of antigen. As this process continues, the aggregates of antigen molecules and antibody molecules become larger and larger until finally they constitute a visible precipitate. Thus the phenomena of agglutination and serological precipitation do not require any further explanation, once the power of formation of a specific bond between antibody and antigen has been explained and a mechanism of providing an antibody with two combining groups has been revealed. Not all antisera have the power of serological precipitation; the non-precipitating antisera presumably contain univalent antibodies with only one combining group.

Landsteiner discovered a specially interesting way of studying the degree of specificity of antibodies. He found that when benzoic acid itself was added to an anti-*p*-aminobenzoic acid serum no precipitate was formed. However, a reaction had occurred between the benzoate ions and the antiserum, because when the homologous azoprotein was added to the solution it failed to precipitate with its antiserum, which in the absence of the benzoate ion would have given a precipitate with it. This inhibition of precipitation by the simple haptenic benzoate ion was explained by Landsteiner as resulting from the formation of a soluble complex between the antibody and the benzoate ion. The framework theory of serological precipitation and the assumed bivalency of antibodies immediately provide an explanation of the phenomenon: the bivalent antibody is able to combine with two molecules of benzoate ion, one of which attaches itself to each of its combining groups, but it is not able to form a framework precipitate with benzoate ion, because the benzoate ion ('antigen') itself has the power of combining with only one antibody molecule. The azoprotein antigen, with several *p*-azobenzoate ion haptenic groups, can form the framework in the absence of benzoate ion, but in the presence of benzoate ion all the antibody is tied up in soluble complexes with this ion, and so is prevented from precipitating.

Continuing the work of Landsteiner, Professor Dan H. Campbell, Dr David Pressman, and I, with a number of students, have carried out quantitative studies of the relative inhibiting powers of a great number of haptens, and have in this way obtained detailed information about the closeness of fit of the combining region of the antibody to haptenic groups of known structure. It has been found that, in general, the replacement of one group by another group that differs in shape from it by as much as one or two Ångström units leads to a significant decrease in combining power with the antibody. For example, the introduction of a methyl group in place of a *meta* hydrogen atom in the benzene ring of the benzoate ion decreases the combining power with an anti-*p*-aminobenzoic acid serum to about one-tenth of its original value. This is explained as the result of a resistance to fitting the larger methyl group, which has an effective radius of about 2·0 A, into the region which in the process of synthesis of the antibody was occupied by a hydrogen atom of the haptenic group of the immunizing antigen, this hydrogen atom having an effective radius of about 1·2 A. It has also been shown that a negatively charged group is present in the antibody at very nearly the minimum distance of approach to a positively charged group in the haptenic group of an azoprotein used in producing the antiserum [7].

An example of the degree of the effect of molecular shape on the power of combining with an antibody is illustrated in figures 3–6. Figure 3 gives a representation of the *p*-azosuccinanilate ion group, present with many other similar groups in an azoprotein molecule, used in the production of an anti-*p*-azosuccinanilate antiserum by injection into rabbits. Figure 4 shows a schematic drawing of the combining regions of such an antiserum, surrounding the haptenic group. It will be noticed that the atoms that constitute the surface of the combining region of the antibody are shown as being in approximate (about 1 A) contact with the surface of the atoms of the haptenic group. It seems likely that there is still closer approximation of the surface atoms of the antibody and the antigen in many cases, and that the antibody has enough elasticity to permit the introduction of haptens that differ in shape by 1 or 2 A in linear dimensions from the haptenic group of the immunizing antigen. An ammonium ion group, with a positive charge, is indicated in the drawing as at the minimum distance of approach to the negatively charged carboxyl group of the succinanilate hapten, and an $\diagdown$NH$\diagup$ group, capable of forming a hydrogen bond with the carbonyl group of the succinanilate, is shown in the proper position to form this hydrogen bond.

The maleanilate ion:

$$C_6H_5.NH.CO.CH=CH.COO^-$$

and the fumaranilate ion (with the same formula) are closely similar substances, differing only in their spatial configuration, the maleanilate ion having the *cis* configuration about the carbon–carbon double bond and the fumaranilate ion having the *trans* configuration about this bond. These ions were found to differ very greatly in their inhibiting power for anti-*p*-azosuccinanilate serum. The maleanilate ion has nearly as great an inhibiting power as the homologous hapten succinanilate ion itself, whereas the fumaranilate ion has a very slight effect, only about 1 per cent. of that of the maleanilate ion. This power of the antibody to distinguish between two ions of such closely related structure was discovered by Landsteiner, and has been verified through the study of hapten inhibition by hundreds of substances. The relatively small difference in structure of the fumaranilate ion and the maleanilate ion is shown by the drawings in figures 5 and 6.

The importance of a positive charge in the antibody is indicated by the fact that no haptens except those with a negatively charged group—either a carboxyl ion group or a closely similar ion group—have any power of combination with antibodies homologous to the *p*-azosuccinanilate ion. The presence of the indicated hydrogen-bond-forming group in the antibody molecule, shown as combining with the carbonyl group, is verified by the fact that only haptens that contain this carbonyl group have a significant power of combining with the antibody.

It is interesting that a study of serological reactions can be used to provide information about the molecular structure and configuration of simple substances [8]. Thus it might be thought that the *p*-azosuccinanilate ion group, indicated in figure 3, would have an extended configuration, somewhat similar to that shown for the fumaranilate ion, inasmuch as there is considerable freedom of rotation about the carbon–carbon bond. However, from the fact that the maleanilate ion has a large combining power with anti-*p*-azosuccinanilate ion antibodies, while the fumaranilate ion has a small combining power, it can be deduced that these antibodies are complementary in configuration to the maleanilate ion, and that consequently the *p*-azosuccinanilate ion group, which serves as the template for the manufacture of these antibodies, itself has a configuration closely similar to that of the maleanilate ion. This configuration, shown in figure 3, is presumably stabilized, relative to the *trans* configuration, by the formation of an N—H . . . O hydrogen bond between the imino group and an oxygen of the carboxyl group. The fact that the succinanilate ion itself, other amides of succinic acid, and the mono-alkyl esters of succinic acid also combine strongly with the antiserum shows that these ions tend to assume a similar *cis* configuration. However, the succinate ion ($^{-}OOC.CH_2.CH_2.COO^{-}$) has a surprisingly small power of combination with the antiserum—approximately that of the fumarate ion, and much smaller than that of the maleate ion—from which it can be inferred that the succinate ion has essentially a *trans* configuration about the carbon–carbon single bond. An obvious explanation of the stability of the *trans* configuration for this ion is the Coulomb repulsion of the two negatively charged carboxyl groups.

In a preceding paragraph a rather complicated mechanism for the manufacture of antibodies with two combining groups has been described. The existence of these bivalent antibodies is presumably explained by their usefulness in causing the agglutination of cells or the precipitation of molecular antigens. However, the lysis and phagocytosis of cells are aided by the attachment of antibodies to the cells, but seem not to require agglutination; hence this part of the mechanism of protection against disease might be just as well done by univalent as by bivalent antibodies. Similarly the neutralization of toxins is effectively achieved by univalent antitoxins, and the reason for the manufacture by animals of bivalent antitoxins is here also not clear.

Nevertheless the phenomena of agglutination and serological precipitation are striking ones, and it is of interest to see whether they can be explained by the same forces that produce specific combination of antibody and antigen, or whether some additional explanation must be invoked. In suggesting that the first of these alternatives is correct, and that agglutination and precipitation result from multivalency of the antibody, Marrack [6] adduced various experimental observations in support of his proposal. Further support for the framework theory was provided by the work of Heidelberger and Kendall [9].

Recently a striking experiment was carried out, the results of which leave little doubt that the framework theory of serological precipitation and agglutination is correct [10]. Landsteiner and van der Scheer [11] had observed that certain simple substances containing two haptenic groups were able to produce precipitates with the hapten-homologous antisera. It seemed to us likely that

the formation of a precipitate with these substances, containing two haptenic groups, and the failure to form precipitates with substances containing only one haptenic group, which in general have only an inhibiting power, due to the formation of soluble complexes, could be explained directly by the framework theory, and that accordingly a test of the theory could be made by investigating a large number of monohaptenic and polyhaptenic substances. This was done with the use of antisera homologous to the *p*-azobenzenearsonate ion group [12]. It was found that of the substances tested those containing two or more *p*-azobenzenearsonate ion groups in the molecule produced precipitates with the antisera, there being about twenty of these substances, whereas the thirty substances tested which contained only one benzenearsonate ion group in the molecule did not form precipitates but rather inhibited precipitation with a precipitating antigen.

The argument might be made, however, that the tendency of the polyhaptenic molecules to form precipitates with the antisera is due to some property other than their polyhaptenic character, and that only one of the haptenic groups may be actually involved in combination with antibody. A test was made by carrying out a special experiment [10], the results of which showed that each of the two haptenic groups of a dihaptenic substance enters into specific combination with antibody in the formation of the serological precipitate.

It was found that antisera could be obtained from two rabbits, and a substance could be synthesized of such nature that neither of the two antisera alone forms a precipitate with the substance, but that a mixture of the two antisera, from the two rabbits, has the power of precipitating with the substance. This serological reaction is, then, one involving a substance of known structure, which serves as precipitating antigen, and two different antisera, which must co-operate in producing the precipitate with the substance.

One of the rabbits was injected with an azoprotein containing R groups (*p*-azobenzenearsonate ion groups), and the other rabbit was injected with a protein containing X groups (*p*-azobenzoate ion groups). The two antisera are accordingly an anti-R serum and an anti-X serum. Each of these sera is able to form a precipitate with substances containing two or more of the homologous haptenic groups. The two RX substances used in the experiment were made by coupling one R group and one X group to a molecule of known structure; the substances were 1-amino-2-*p*-(*p*-azobenzeneazo)-benzenearsonic acid-3,6-disulphonic acid-7-*p*-(*p*-azobenzeneazo)-benzoic acid-8-hydroxynaphthalene and 1,8-dihydroxy-2-*p*-azobenzenearsonic acid-3,6-disulphonic acid-7-*p*-(*p*-azobenzeneazo)-benzoic acid-naphthalene. Each of these substances was found to form no precipitate (or only a very slight precipitate) with either anti-X or anti-R serum alone, but to form a large amount of precipitate with a mixture of these two antisera. This observation provides strong evidence that the precipitation of antibody and antigen involves both the haptenic groups of the dihaptenic antigen. When mixed with anti-R serum alone, a substance RX uses its R groups to combine with the anti-R antibodies, two molecules of RX thus forming a soluble complex with one molecule of bivalent antibody; but because the molecules RX are effectively monohaptenic when only anti-R antibodies are present, a framework precipitate cannot be formed. In the presence of a mixture of anti-R and anti-X antibodies, however, the molecule RX is effectively bivalent, and can form a framework in which the anti-R and anti-X antibodies alternate.

There is now very convincing evidence that the specificity of combining power of antibodies can be explained in terms of short-range forces of known nature, the specificity itself resulting from complementariness in structure of the combining region of the antibody and the surface of the homologous antigen. It seems not unlikely that biological specificity in general is to be accounted for in a similar manner, as resulting from the ordinary non-specific, short-range forces that operate between all molecules, with the specificity of the forces in the biological systems due to the complex surface configuration of the large molecules present in these systems. The evidence as to the nature of the biological forces in systems other than serological systems is, however, not so extensive. Phenomena such as competition between the sulphonamide drugs and *p*-aminobenzoic acid, and the inhibition of enzyme systems generally by substances related in structure to those that take part in the catalysed reaction, suggest, by their similarity to hapten-inhibition of serological precipitation, that the same forces are acting as in the serological systems. For example, the malonate ion serves to inhibit the catalytic activity of the enzyme dehydrosuccinase, presumably by competing with the succinate ion for the position of attachment to the active region of the enzyme. The fact that the malonate ion is especially effective as an inhibitor of this catalyst may be significant with respect to

the mechanism of catalytic activity. If the catalytically active region of the enzyme were closely complementary in structure to the succinate ion it would presumably not accelerate the reaction of dehydrogenation of the succinate ion, but would instead retard it, since by combining with the succinate ion it would stabilize this ion, and thus increase the amount of energy necessary to convert the ion into the activated complex for the dehydrogenation reaction. If, however, the enzyme were more closely complementary in structure to the activated complex itself than to the succinate ion, it would decrease the activation energy for the reaction, and in this way speed the reaction up. The effectiveness of the malonate ion in inhibiting the reaction suggests that this ion is more closely similar in structure to the activated complex of the dehydrogenation reaction for succinate ion than is the succinate ion itself, and that it is for this reason that the malonate ion is able to compete effectively with the succinate ion for the position on the active region of the enzyme.

It seems unlikely that the specific differences between related enzymes produced by animals of different species, or between other proteins, such as haemoglobin, are due to so simple a difference in structure as a different way of coiling the polypeptide chains. It is probable that antibodies are unique in using this mechanism alone for the assumption of specific differences, and that other biological macromolecules depend upon more deep-seated changes in structure to produce these differences in specific properties. In particular, I think it likely that in general a mutation is due not simply to a changed way of coiling the filamentous structural unit of the gene nucleoprotein, but to a change in the composition of this unit which affects its catalytic activity in such a way as to permit the controlled manufacture of duplicates of itself, with the changed structure. It seems likely that a gene that is damaged by ultraviolet light or X-radiation or other catastrophe in such a way as ultimately to produce a mutant is not itself the mutated gene, but is simply a damaged gene. It might be damaged so badly as to be unable to carry on an essential function in the development of the organism, the damage then being lethal. Or the damage might be of such a nature as to permit the gene to serve as the template and to exercise its other functions so as to produce replicas of itself as it was before it was damaged. Or again it might happen that the damaged gene could carry out its functions and produce new genes of somewhat changed structure, which themselves could serve as templates, until ultimately a steady state was achieved, at which there would be no difference between the gene that served as the template and the gene produced with it is as a model. This would be the phenomenon of mutation.

There is at present little reliable evidence as to the detailed nature of the process of production of replicas of complex biological molecules, such as viruses or genes, but it is clear that the phenomenon of production of complementary structures, as in antibody formation, provides a possible mechanism. The manufacture of a replica, of a gene for example, might require the production of an intermediate, the gene producing a molecule complementary in structure to itself, which in turn serves as the template for the reproduction of a replica of the original gene. Some support for this concept is given by the known existence of complementary structures in living organisms, such as the blood-group antigens and their homologous agglutinins, and the mutually complementary substances found in eggs and sperm [13].

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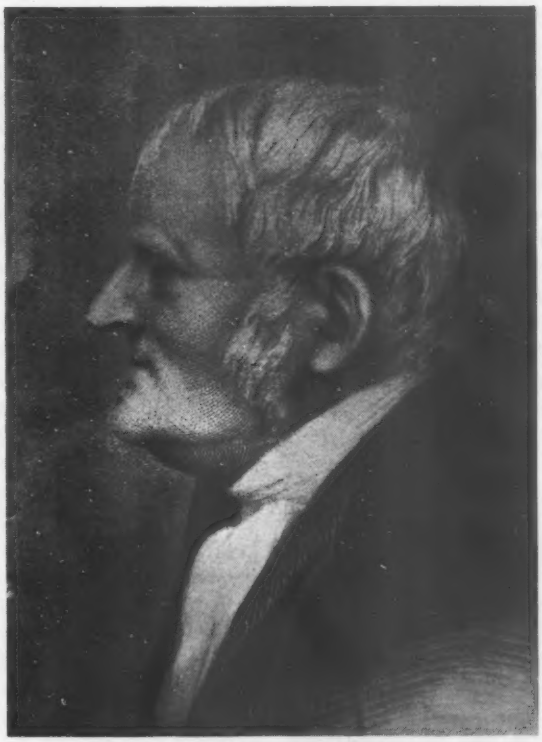
John Dalton

J. R. PARTINGTON

The belief that matter consists of atoms had been debated by philosophers from the days of Empedocles. Dalton gave the theory precise formulation and applied it to chemical problems. His theory enabled him to explain all the laws of chemical combination then known, and it is a tribute to his genius that, although much modified and extended, his atomic theory is still the foundation of the whole of chemistry. Professor Partington suggests that Dalton was led to his discoveries by his prolonged study of the constitution of the atmosphere.

John Dalton was born at Eaglesfield, a village near Cockermouth in Cumberland, remote from the main centres of commerce and learning. His parents and ancestors were artisans, not peasants, and although the parents were in modest circumstances they had a small estate: they were 'statesmen' in local speech. They belonged to the Society of Friends, of which body John Dalton was a member throughout his life, and in consequence there is no record of his birth in the parish registers, the date (6th September, 1766) being recalled long afterwards in the memories of neighbours of his parents. His father, a wool-weaver, taught him arithmetic; at the age of 10 he was given lessons in mathematics by Elihu Robinson, a wealthy Quaker of scientific attainments, and also attended a school, where he had the reputation of being steady and persevering but not brilliant. At the age of 12 he himself set up a school, but had difficulty in controlling boys older and bigger than himself. In 1781 he and his brother went as assistants in a school at Kendal, which they took over for themselves in 1785, teaching Greek, Latin, French, and mathematics as well as English subjects. The languages and mathematics were acquired by John as a result of hard study, in which he was encouraged and helped by John Gough, a blind Quaker of exceptional gifts. In the winters of 1787 and 1791 Dalton gave courses of lectures on natural philosophy, including chemistry. His knowledge of chemistry was acquired from the works of Boerhaave and Boyle, and the *Essays* of Bishop Watson. While at Kendal he had probably studied Newton's *Principia* with Gough. In 1793 he was appointed, on Gough's recommendation, as tutor in mathematics and natural philosophy in New College, Manchester, a Dissenting institution in Mosley Street, which was the outcome of the Warrington Academy. He also taught chemistry, using Lavoisier's *Elements of Chemistry*. Dalton remained in Manchester for the rest of his life; when New College moved he supported himself by private tuition, giving lessons in grammar, arithmetic, and science for a fee of 1s. an hour, later raised to 1s. 6d. One of his pupils was Joule. He published *Elements of English Grammar: or a New System of Grammatical Instruction* in 1801. In 1824 he gave some lectures to medical students.



John Dalton, 1766–1844.

Dalton's discovery in 1792 of colour-blindness in himself was announced in 1794, and there are

some amusing anecdotes of the results of this defect of vision. He joined the Manchester Literary and Philosophical Society in 1794, became vice-president in 1808, and was president from 1817 to 1844. He read over a hundred papers to the society, in the rooms of which many relics of Dalton were preserved until their destruction by fire, an indirect result of German incendiary bombs, in 1940. He dressed well but plainly, and had regular habits, on one day of the week playing bowls. His health was good until a few years before his death, and he was a sturdy mountain climber, easily outstripping most of his companions. He never married, saying that he had no time, but he was fond of the society of educated women. Although much in request as a lecturer, he was somewhat uncouth, with a harsh deep voice, and once gave offence by calling the chemical elements 'articles,' as though, it was said, he was a grocer and not a 'natural philosopher.' As an experimenter he was lacking in accuracy; his apparatus, consisting of penny ink-bottles, bits of tubing, and the like, would seem contemptible to many, but he was not often misled by the results. In the difficult department of gas analysis he had unusual skill.

Dalton was somewhat above middle height, with a robust and muscular frame and a slight stoop. His face had some resemblance to Newton's, especially in later life. In 1833 a subscription of £2,000 was raised in Manchester for a marble statue by Chantry, now in the Town Hall, where there is also a fresco by Ford Madox Brown showing Dalton collecting marsh gas from a pond. There is a marble bust by Cardwell in the University library.

Before Dalton had become well known, he lectured, at Davy's invitation, at the Royal Institution, London, in 1803–4, and again in 1809–10, receiving some instruction in the art of lecturing from his brilliant colleague. When he delivered some lectures in Edinburgh his audience was scanty, but in Glasgow in 1807 he had a very good reception. Dalton became F.R.S. in 1822 and received the Royal Medal in 1826; he was elected one of the eight foreign associates of the French Academy in 1830, became D.C.L. of Oxford in 1834, and in 1833, after representations to the Government by Mr. Babbage, was granted a civil pension, which was increased in 1836 to £300 a year. On 27th July, 1844, he died from a stroke, and was given an impressive public funeral. Honours, therefore, were freely bestowed on Dalton during his life, and he enjoyed the esteem of the whole scientific world.

From his early days Dalton kept a meteorological diary, and made daily entries in this until the morning of his death, his last act being to inscribe 'little rain this,' adding feebly 'day,' so ending his life in a scientific observation. His book *Meteorological Observations and Essays*, published in 1793, a second edition appearing in 1834, contains the germ of his later discoveries, which seem to have begun with a consideration of the state of water vapour in the atmosphere. Newton, in the *Principia*, had adopted the idea that the pressure of air was due to repulsion of the particles by a force varying inversely as the distance. The kinetic explanation that it was due to bombardment by moving particles, given by Bernoulli in 1737, had not been taken up. The atomic theory, from the time of its enunciation in ancient Greece, had never been lost sight of, and Newton, in his *Opticks*, had made extensive use of it. He seems almost to have suspected that different atoms might have different masses, and he certainly assumed that they had different sizes and shapes; the question as to whether they were divisible, he said, could be settled only by experiment.

Lavoisier had used the idea of atoms, and in his *Elements of Chemistry* (1789) he taught that a gas consists of small particles, between which there are particles or 'molecules' of the fluid of heat (caloric), the repulsion of which keeps the gas molecules apart and gives rise to pressure. Lavoisier had shown that the atmosphere contains two gases, oxygen and nitrogen, as well as water vapour, while Newton assumed that air contained one kind of particle only. Some thought the atmosphere was a chemical compound, so explaining why its composition was constant, and why the heavier oxygen did not separate from the nitrogen. The state of the water vapour was undecided. It was the prolonged and persistent study of the problem of the constitution of the atmosphere which led Dalton to the chemical atomic theory.

In 1793, in his *Meteorological Observations and Essays*, he asserted that pure air is 'an intimate mixture of various elastic fluids or gases,' and that 'if we adopt the opinion, which to me seems the more probable, that water evaporated is not chymically combined with the aerial fluids, but exists as a peculiar fluid diffused amongst the rest,' the phenomena of rain and dew are easily explained. A paper in *Nicholson's Journal* in 1801 on 'A New Theory of the Constitution of Mixed

Aeriform Fluids and particularly of the Atmosphere' was extended by four essays, read in 1801 to the Manchester Literary and Philosophical Society, which gave Dalton a European reputation; they contain his 'law of mixed gases,' or law of partial pressures, which he says in his *New System* (1808) was 'hit upon' in the autumn of 1801. This law was equivalent to the assumption that, as Henry said in 1804, in a mixture of gases, each gas 'is a vacuum to every other gas.' In speculating how this could be reconciled with mutually repelling particles of different gases, Dalton seems to have arrived at the view that the particles of different gases have different weights. He made much use of diagrams, some reproduced in his book, showing the 'ultimate particles' of gases as small spheres, surrounded by atmospheres of caloric. In his lectures he also used cubical wooden blocks to represent atoms, and a student's definition of atoms as 'small blocks of wood, painted in different colours, invented by Dr Dalton,' was based on these visual aids to memory. Dalton also used wooden balls with holes to be connected by pins.

The earliest entry in Dalton's notebook giving a table of atomic weights is dated 6th September (his birthday), 1803; the values (hydrogen 1, oxygen 5·66, azote 4, carbon 4·5, etc.) are mostly based on Lavoisier's analyses. The first announcement of the subject is at the end of a paper read on 12th November, 1802, to the Philosophical Society, but first printed in 1805, describing some experiments on mixing air and nitric oxide over water; these first appear in Dalton's notebook in the period October–November 1803, and were added after the paper was read. They showed 'that oxygen may combine with a certain portion of nitrous gas or with twice that portion, but with no intermediate quantities.' In a footnote in the printed paper he says: 'An enquiry into the relative weights of the ultimate particles of bodies is a subject, as far as I know, entirely new: I have recently been prosecuting this enquiry with remarkable success. The principle cannot be entered upon in this paper; but I shall just subjoin the results, as far as they appear to be ascertained by my experiments.' Then follows a table of 'relative weights of the ultimate particles of gaseous and other bodies,' the first table of atomic weights, every entry in which (except the standard, hydrogen = 1) is incorrect.

In 1804 Thomas Thomson visited Dalton in Manchester, and in 1807 he gave the earliest detailed account of Dalton's atomic theory in the third volume of the third edition of his *System of Chemistry*, the first volume of Dalton's own *New System of Chemical Philosophy* not appearing until 1808, and containing only a short section on the theory. In his *History of Chemistry* (1830–1), Thomson gave the origin of Dalton's theory in his detection of multiple proportions in analyses of marsh gas and ethylene by explosion with oxygen, but the theory was in existence at least a year, and probably longer, before these analyses were made to confirm it. It arose from speculations on mixed gases, made with the object of reconciling Newton's theory of the atmosphere (assuming it to be an element) with the new knowledge that it is a mixture of two permanent gases and water vapour.

Dalton's estimates of atomic weights were based on some empirical rules, the first of which was that if only one compound of two elements is known its 'compound atom' contains one atom of each element, 'unless some cause appear to the contrary'; this was based on the idea of the repulsion of atoms of the same kind. The particles of oxygen, nitrogen, etc., were assumed to be atoms, not molecules composed of two atoms. Dalton did not accept Avogadro's hypothesis and doubted the accuracy of Gay-Lussac's law of volumes.

Although his own circular symbols were very inconvenient, Dalton never adopted Berzelius's symbols (which are still in use), saying, in fact, that they were 'horrifying.' His great conservatism was also shown in his refusal to accept Davy's views of the composition of the alkalis, earths, and chlorine. Some papers declined by the Royal Society he issued in book form in 1840–2, with a preface which shows that he felt this action keenly; they contain some important observations and should have been published. Joule's work was rejected by the Royal Society about the same time.

The atomic theory had been known from the time of the Greek philosophers, and some applications of it to physical problems had been made before Dalton. His contribution lay in adapting it to the needs of chemistry by attributing different weights to the atoms of the different chemical elements, and, by assuming combining ratios between the atoms which seemed to him probable, making it possible to calculate the relative weights of atoms from the combining ratios of masses. These results at once explained all the known laws of chemical combination. The later extensions of the theory have broadened and deepened its content, but in its main outlines it still remains Dalton's atomic theory.

The polarization microscope

B. K. JOHNSON

Although the polarization microscope has been used for many years in geological and mineralogical investigations, its potential value in the metallurgical, biological, and chemical fields is perhaps not yet fully appreciated. In this article the fundamental principles involved in the use of the polarization microscope are described, and examples are given of the way in which it can be applied to practical problems, especially in these new fields.

The use of polarized light in conjunction with the microscope has been the means of adding considerably to the usefulness of this instrument for particular branches of science. Among these, perhaps geology must have the first claim, for Sorby's original work in this connection dates back to 1860. Much valuable work has been done with the polarization microscope since that time, and in more recent years it has become of service to workers in the fields of biology and metallurgy.

The appearances of certain kinds of objects when viewed through the polarization microscope considerably assist the microscopist in the identification of a specimen, and this in a manner not possible by ordinary observation with unpolarized light. For instance, the identification of minute particles of crystals, minerals, etc., can be effected by this means; in biological specimens differentiation of fibrous membranes in other tissue may be greatly facilitated; and in metallurgical specimens inclusions may sometimes be identified and stress effects observed.

Before dealing with the polarization microscope itself, a few remarks must be made on polarization phenomena in general—without, however, going into a lengthy treatment of the subject.

Plane-polarized light may be produced:

1. By reflection at a polished surface at the appropriate angle.
2. By transmission through a Nicol prism or modification of this form of prism.
3. By transmission through a plate of tourmaline cut parallel to the optic axis.
4. By transmission through plates of Polaroid (a compound of iodine and quinine sulphate crystallizing in the form of thin, flat plates).

If two polarizing devices are arranged in optical train and so orientated that the vibration directions of light transmitted by them are parallel, light will pass to an eye placed behind the second polarizer (sometimes called the analyser). If, however, one of them be rotated so that its plane of vibration is now at right angles to that of the other, no light will pass to the eye. The latter condition is frequently spoken of as 'crossed Nicols' and the former as 'parallel Nicols.'

If we place between crossed Nicols certain specimens such as a sheet of glass, quartz, Cellophane, or selenite (i.e. calcium sulphate) and rotate them in their own plane perpendicular to the direction of vision, we find that as the rotation continues they behave differently with respect to the transmission of light. For instance, the glass (provided it is homogeneous and free from strain) will have no effect on the dark field given by the crossed Nicols; the quartz, however, will appear alternately dark and light at each 45° of rotation (see figure 10*a* and *b*); the piece of Cellophane (if thin and of uniform thickness) will appear coloured; and the thin plate of selenite (which usually cleaves in layers of varying thickness) will give a multi-coloured appearance when placed at 45° between the crossed Nicols. This effect is illustrated in figure 1.

The effects seen with the last three materials mentioned are due to their bi-refracting nature. The well-known property of double refraction of certain media may be demonstrated by Huygens' early experiments, in which a rhomb of Iceland spar (calcite) is placed over some print, when two images will be seen instead of a single image (figure 12). In a second experiment (figure 13) an illuminated slit may be viewed through a polished crystal of quartz, when two spectra will be seen; if then a polarizing device is placed in turn in each of the beams, it will be found that each beam is itself plane-polarized but that their vibration-directions are mutually perpendicular. A further important point we may learn from this experiment is that as the two beams are deviated by different amounts, the refractive index of the material for the two beams must be different;

hence the two beams travel with different velocities through the medium.

We may thus arrive at the following fundamental conclusion, namely that if a beam of light enters a bi-refracting material it is split up into two beams, vibrating at right angles to each other and travelling with different velocities through the material.

This helps us to understand many of the polarization phenomena we observe. For instance, the colour of a thin plane-parallel plate of some bi-refracting substance when placed at 45° between crossed Nicols and illuminated by white light is due to the fact that the two beams travelling with different velocities through the plate get out of step or out of phase by half a wavelength of one colour of the spectrum; hence this colour is eliminated by interference, and the final appearance of the specimen is white minus that portion eliminated.

Such explanations are, however, not fully adequate, and the matter can be better understood only by a much closer study of polarization phenomena generally. The reader will do well to consult the references given [1, 2, 3, 4], as the limited space in an article of this size does not permit detailed explanations.

The advantage of using polarized light in various branches of work is clearly illustrated by comparing the coloured photomicrographs of figures 1, 2, and 3 with the corresponding appearances in unpolarized light.

Turning now to the accessories required for converting an ordinary microscope into a polarization microscope, it is sufficient in the case of simpler instruments to employ two polarizing devices, one mounted immediately in front of the substage condenser and the other conveniently arranged over the top of the eyepiece but capable of being swung out of position when desired. Both polarizer and analyser are arranged to rotate about the microscope axis, as is also the stage on which the specimen rests. In more advanced instruments mechanical modifications are made in order to permit the introduction of certain optical devices for carrying out particular tests on the specimens. For instance, provision must be made in the side of the body-tube for inserting such things as a retardation wedge, a wave-plate, and a Bertrand lens, the purposes of which are described later. The optical system, therefore, for a polarization microscope becomes as depicted in figure 14. P is the polarizer (usually a Nicol prism) situated immediately beneath the condenser C; it can be rotated about a vertical axis. S is the rotating stage on which the specimen is placed, O the microscope objective, E the eyepiece, and A the analyser, which may consist of a small Nicol prism, a plate of tourmaline, or a Polaroid plate. The named optical parts on the right of the figure are some of the required auxiliary devices, and the positions at which they slide into the body-tube are indicated.

MEASUREMENT OF BI-REFRINGENCE

One of the more important measurements which can be made with the polarization microscope is the numerical determination of the bi-refringence of a minute piece of a specimen, for this is frequently the keynote to its identification.

The difference in the refractive indices ($N_1 - N_2$) of the material for the two beams is known as its bi-refringence; and as substances are often tabulated in order of their bi-refracting power[1] the identification of the specimen is thus rendered possible.

The determination is effected by a measurement of the retardation R of one beam with respect to the other as they pass through a plate of the substance, and by a measurement of its thickness t. The bi-refringence ($N_1 - N_2$) is equal to R/t.

The measurement of the retardation R is carried out by an optical device known as a retardation wedge, which consists of a thin wedge of some uniaxial bi-refracting material (e.g. quartz) cut with its surfaces parallel to the optical axis (see figure 11). If such a wedge is placed between crossed Nicols, inclined at 45° to the vibration-direction of the polarizer and illuminated by monochromatic light, dark interference bands will be seen at positions along the wedge where the thicknesses are such that the retardation between the two beams (set up by the bi-refracting nature of the quartz) is a half-wavelength, or an odd multiple of a half-wavelength, of the monochromatic light used. For example, figure 5 shows such a wedge illuminated by monochromatic red light ($\lambda = 6{,}200$ A); the interference bands and their relative positions on the scale can be seen.

If, however, the wedge is illuminated by white light instead of monochromatic light, a series of interference colours is seen, each colour corresponding to a particular retardation. Figure 4 illustrates these 'order of polarization colours' as they are called. Starting from black, when the thickness of the wedge is zero, bluish-grey tints

[1] *Manual of Petrographic Methods*, p. 373, ref. 5.

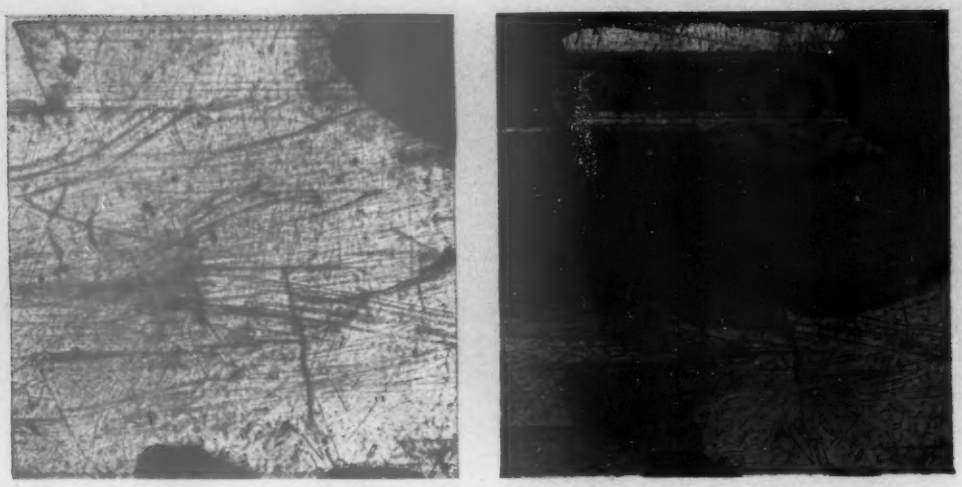


FIGURE 1 – *A cleavage plate of selenite as seen (left) with unpolarized light and (right) when viewed in polarized light.*

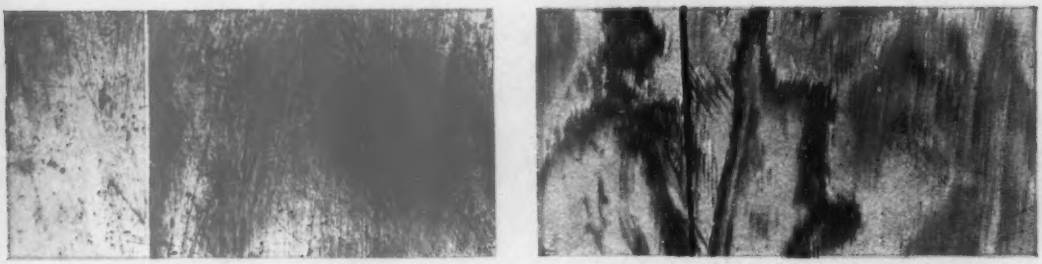


FIGURE 2 – *Photomicrographs of a thin section of natural horn taken in (left) unpolarized light and (right) polarized light. The same part of the object has been photographed in each case.*

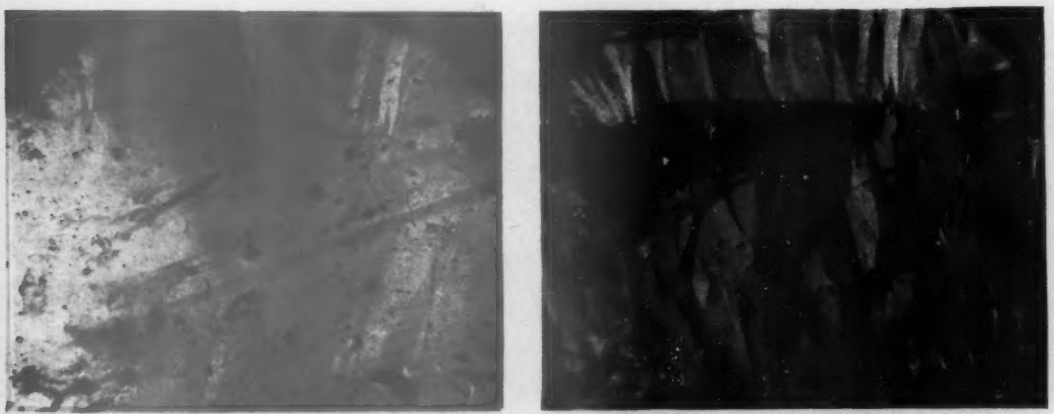


FIGURE 3 – *Photomicrographs of an opaque object (namely copper sulphide) taken in (left) unpolarized light and (right) polarized light. The same part of the specimen has been photographed in each case.*

FIGURE 4 – *Order of polarization colours. The calibrated scale superposed on the colours aids in determining the retardation from the colour (e.g. scale reading* 10 *corresponds to* 1 *micron retardation).*

FIGURE 5 – *Interference bands seen when a retardation wedge is illuminated by monochromatic light.*

FIGURE 6 – *Measurement of retardation by superposing image of specimen on to wedge.*

FIGURE 7 – *Measurement of retardation by means of a wave-plate.*

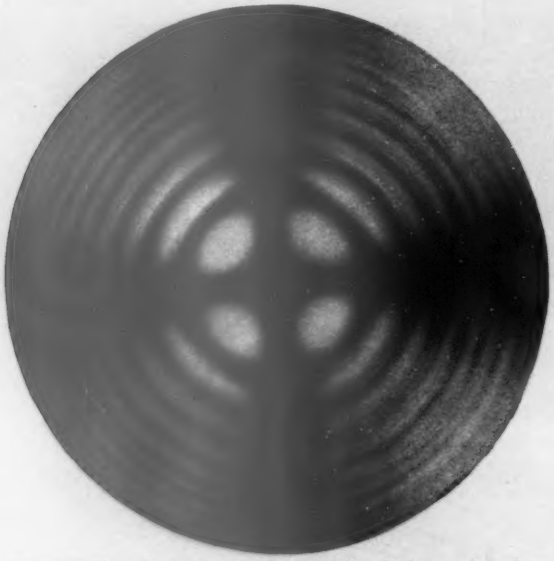


FIGURE 8 – *Characteristic ring and brush figure given by a uniaxial crystal seen in convergent polarized light.*

FIGURE 9 – *'Two eye' appearance given by a biaxial crystal viewed in convergent polarized light.*

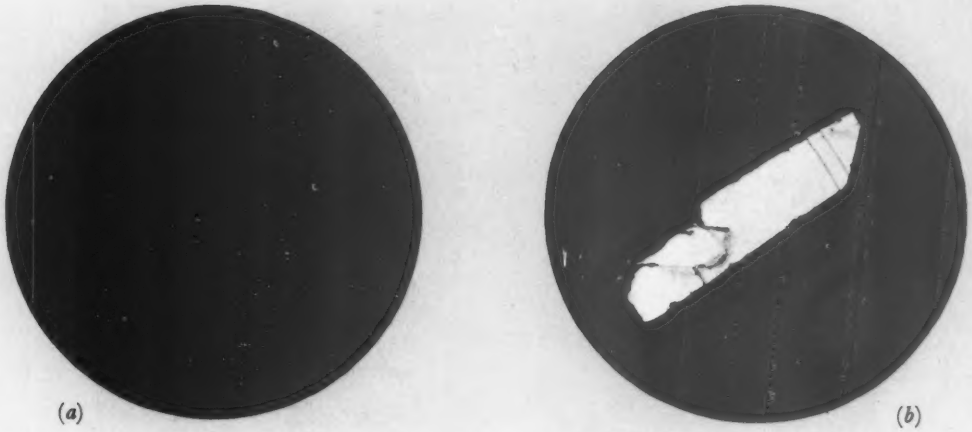


FIGURE 10 – *A small quartz crystal as seen between crossed Nicols, (left) when placed parallel to the vibration direction of the polarizer, (right) when placed at 45° to the vibration direction of the polarizer.*

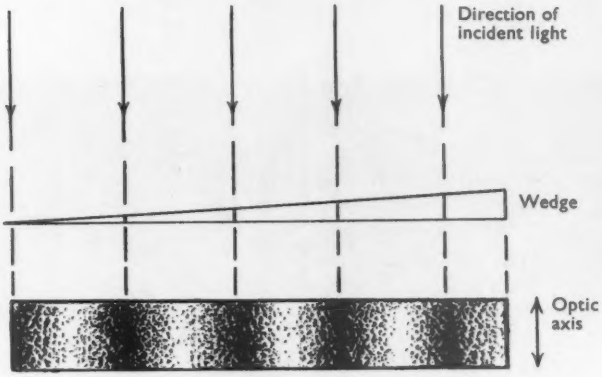


FIGURE 11 – *Diagrammatic representation of the effect of a wedge consisting of some uniaxial bi-refracting material such as quartz. Bands are formed when the thickness of the wedge is such that the retardation between the two beams is a half-wavelength, or an odd multiple of a half-wavelength.*

FIGURE 12 – *Double refraction produced by a rhomb of calcite.*

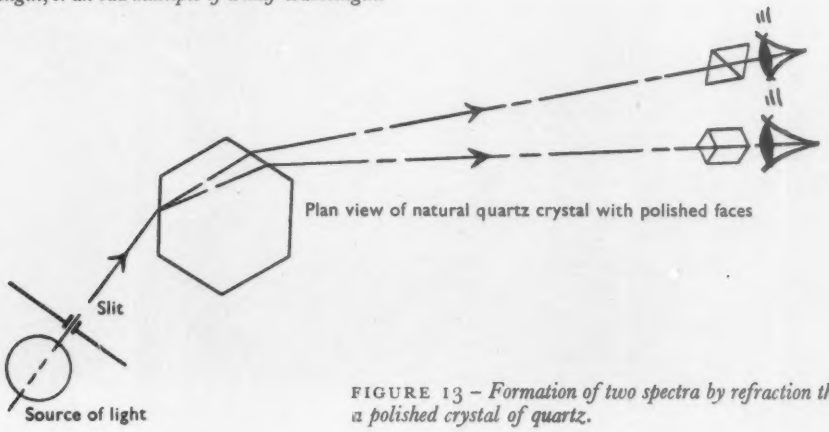


FIGURE 13 – *Formation of two spectra by refraction through a polished crystal of quartz.*

are the first to appear; they are followed by yellow, orange, red, etc., for positions of increasing retardation. A study of the order of appearance of these colours for known retardations has been made by Quincke. His table is given below:

TABLE OF POLARIZATION COLOURS

Retardation in Microns for $\lambda = 5{,}893\ A$	*Interference Colours between Crossed Nicols*	*Order*
0·00	Black	FIRST
0·04	Iron-grey	
0·097	Lavender-grey	
0·158	Greyish blue	
0·218	Clearer grey	
0·234	Greenish white	
0·259	White	
0·267	Yellowish white	
0·281	Straw-yellow	
0·306	Light yellow	
0·332	Bright yellow	
0·430	Brownish yellow	
0·505	Reddish orange	
0·536	Red	
0·551	Deep red	
0·565	Purple	SECOND
0·575	Violet	
0·589	Indigo	
0·664	Blue (sky-blue)	
0·728	Greenish blue	
0·826	Light green	
0·850	Yellow-green	
0·910	Yellow	
0·948	Orange	
1·101	Violet-red	
1·128	Bluish violet	THIRD
1·151	Indigo	
1·258	Greenish blue	
1·334	Sea-green	
1·426	Greenish yellow	
1·495	Flesh colour	
1·534	Carmine	
1·621	Dull purple	
1·652	Violet-grey	FOURTH
1·682	Greyish blue	
1·711	Dull sea-green	
1·744	Bluish green	

Obviously, then, the *colour* of a specimen seen in polarized light is a valuable indication of the relative retardation, but it might be difficult (except with long experience) to recognize with certainty any one of the many tints given in the above table if it were seen by itself in the microscope. Here lies the importance of being able to insert a retardation wedge into the microscope, for if the coloured image of the specimen and the colours of the wedge are seen simultaneously in the field, the possibility of matching the colour will be apparent. For example, figure 6 shows (at the top) a specimen of a colour which might be described as pink, and by comparing this with the polarization colours given by the wedge (at the bottom of figure 6) we might say that the matching colour was that corresponding to the third order carmine of Quincke's table and having, therefore, a retardation of 1·53 microns. This may be further verified by superposing the image of the specimen over half the wedge, as shown in the centre strip of figure 6, where it will be noticed that the black band at zero retardation has moved along until it is now opposite the previously presumed matching colour, thus proving that this is the correct retardation measurement for the specimen under test. It is then necessary only to measure the thickness of the specimen (which may be carried out either by micrometer screw gauge or depth gauge or by the microscope method), and the bi-refringence can be determined from the relation given earlier.

Another method of measuring retardation is to employ a wave-plate instead of the retardation wedge. The latter is obviously a difficult thing to make, whereas the former is comparatively simple. A wave-plate usually consists of a cleavage plate of mica, of such a thinness that it shows a pronounced and definite polarization colour approximately near the central range of retardations given in the table. In the experiment illustrated in figure 7, the writer has chosen a wave-plate which shows a second order purple colour (retardation 0·565) when placed at 45° between crossed Nicols; if then the image of the specimen is superposed half over the colour of the wave-plate, and if it is rotated on the microscope stage until maximum brightness is secured, then a certain colour (in this case straw-yellow) will be seen. If the specimen is now rotated through 90° we find a yellow-green coloration over that half of the field. By referring to the table it will be noted that in one case the colour has moved down the polarization scale, namely to a retardation value of 0·281, while in the other case a rise in order of colours has occurred (viz. to a retardation value of 0·850). Using the retardation of the wave-plate (i.e. 0·565) as the reference point, we see that the amount the one colour has dropped in the scale (0·565 — 0·281) is the same as the amount the other colour has risen in the scale (0·850 —

0·565). The actual retardation produced by the specimen is thus 0·284 microns.

CONVERGENT POLARIZED LIGHT

In geological work, the use of so-called convergent polarized light is a convenient means of differentiating between uniaxial and biaxial crystals. The respective characteristic appearances seen are shown in figures 8 and 9, but a detailed explanation of these would occupy more space than is here available. For the reader requiring a fuller understanding of these physical phenomena, a closer study will be found in the references already given [1, 2, 4].

When examining crystal sections by convergent light in the polarization microscope, the effective light (already polarized) may be looked upon as originating at points in the lower focal plane of the substage condenser (see figure 15). This light passes through the specimen under observation in parallel bundles at different inclinations to the axis of the microscope; they are brought to a focus in the upper focal plane of the objective, where the polarization effects can be examined. For this purpose an auxiliary lens, known as a Bertrand lens, is introduced into the microscope tube at the position indicated in the diagram (figure 15), which, together with the eyepiece, produces a low-power microscope system for observation of the upper focal plane of the

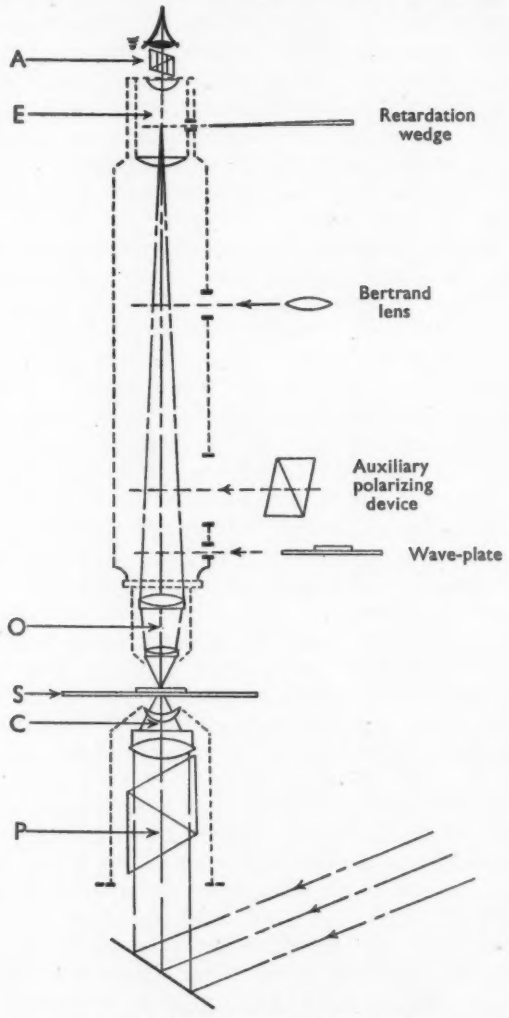


FIGURE 14 – *Optical system of a polarization microscope.*

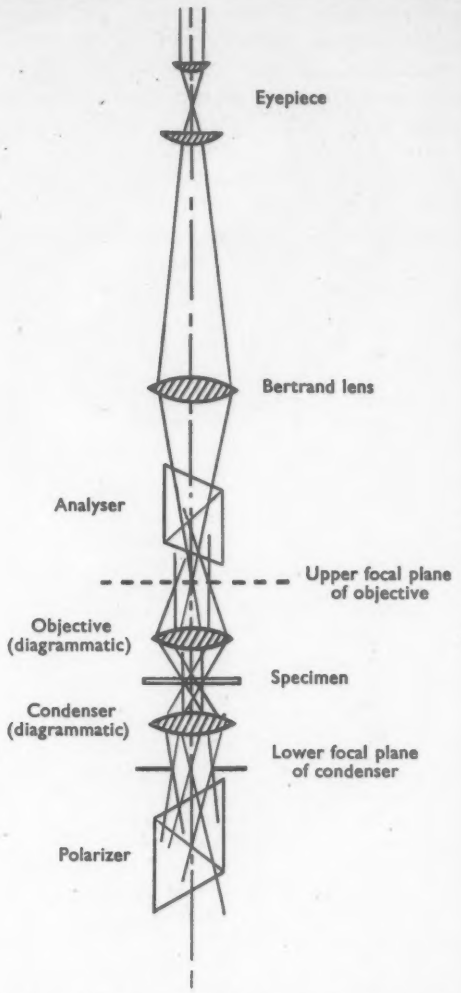


FIGURE 15 – *Arrangement of optical parts for observation in so-called convergent light (diagrammatic only).*

objective. This will be clear from the ray diagram given in the figure, as will also the passage of parallel bundles of differently inclined rays through the specimen. It will be noted that the term 'convergent light' really refers to converging bundles of sets of (polarized) rays passing through the object rather than to a highly convergent *cone* of rays as might at first be interpreted.

With the microscope arranged in this way, it is possible to observe the interference effects produced by the specimen, giving either the 'ring and brush' figure characteristic of a uniaxial crystal or the 'two eyes' appearance of a biaxial.

OPTICAL ROTATION

If a thin plate of quartz be cut with its faces perpendicular to the optical axis and then placed between crossed Nicols in monochromatic light, light is transmitted by the analyser; but on rotating the latter a position will be found where the light is extinguished. It follows, therefore, that the light leaving the quartz plate is plane-polarized, and that the plane in which the vibrations are taking place has been rotated. This phenomenon, which was discovered by Arago in the early nineteenth century and was later fully investigated by Biot, is known as optical rotation. It occurs not only with quartz but with many other crystals and a number of liquids, such as turpentine, nicotine, solutions of sugar, etc.

With a given substance the angle through which the plane of vibration is rotated is proportional to the thickness of the plate;[1] and with a given thickness of material this angle of rotation is inversely proportional to the square of the wavelength of the light employed. In the case of an optically active solution, the rotation for a given thickness of solution is very closely proportional to the weight of the active material dissolved in unit volume of the solution.

These principles have been applied in industrial and other branches of work in the form of polarimeters and saccharimeters, but they may be used also in connection with the polarization microscope. For instance, if the instrument is arranged as in figure 15, but with no object on the stage and with the Nicols parallel, a circular image of the substage iris will be seen in the upper focal plane of the objective. The Nicols are then crossed (giving a dark field), and a reading from the angular scale attached to the polarizer may be taken.[2] If now a piece of, say, axis-cut quartz is placed on the microscope stage, the field will appear illuminated but may be restored to darkness by further rotation of the polarizer. By thus determining the angular rotation produced, and by measurement of the thickness of the specimen, the rotation per millimetre may be calculated; from this information a possible identification of the material may result. These remarks apply also to a liquid contained in a cell of known thickness resting on the microscope stage, although the accuracy in this case will not be particularly great, owing to the smaller angular rotation per millimetre of most optically active fluids, and to the limits in length of the containing cell set by the distance between the microscope objective and the stage. However, such a test may frequently serve as an aid to the identification of a specimen when used in conjunction with the other tests.

In conclusion it will be realized that this article deals only with the general application of polarized light to the microscope, for it is well known that fairly extensive use of the polarization microscope has been made in connection with geology and mineralogy; hitherto it has been less used in the field of biology. Recent work on the X-ray analysis of many organic substances indicates that they have a highly regular arrangement of their constituent molecules and atoms, and behave similarly to bi-refracting materials when examined in polarized light. It follows that a systematic study on these lines (including, for example, the measurement and tabulation of bi-refringence of such substances) might prove extremely fruitful.

[1] E.g. the rotation of the plane of polarization produced by a plate of quartz 1 mm thick is 21·7° for light of wavelength 5,893 A (i.e. the sodium line).

[2] Monochromatic light should be used.

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Structural inorganic chemistry

W. WARDLAW

The scientific investigator, continually occupied with his own problems, often finds little opportunity to reflect upon the past, present, and future of other fields of work. It is with this thought in mind that the writer has attempted to discuss a few of the striking advances in the domain of structural inorganic chemistry, and to mention some of the unsolved problems. Many fundamental conceptions have had to be abandoned or modified in the light of recent work: even the law of constant composition has not come through unscathed.

Most students of chemistry know that Joseph Louis Proust analysed a wide range of substances and in 1799 summarized his conclusions in the law of constant proportion, which states that the same body is invariably composed of the same elements united in the same proportion. In recent years, however, evidence has gradually accumulated—particularly from crystal chemistry—which goes far towards changing our ideas on this fundamental law of chemical combination.

The law of constant proportion is rigidly obeyed when a substance is made up of molecules such as those of nitrogen, carbon dioxide, hydrogen, etc. It applies, too, in full rigidity to binary ionic compounds such as common salt or calcium carbonate. Essentially this means that the law of constant proportion depends on definite directed electron-sharing bonds, or on the necessary equality of positive and negative ionic charges. Compounds may, however, occur in conformity with the law if the conditions of geometrical packing in the crystal are such that the sizes of the various components are very different and the structure well fitted together. Excellent examples are the alums, which exist, of course, only in the crystalline state. When the different units from which the crystal is built differ slightly in size and shape, they may occupy indifferently the same positions. A simple illustration is the mixed crystal containing potassium chloride and potassium bromide. The cell varies continuously as the composition, but the well-known sodium chloride structure is maintained at all concentrations. There is a random distribution of chlorine and bromine ions in the anion positions. It may be objected that the mixed crystals of composition potassium chloride + potassium bromide are not chemical compounds. Some crystallographers maintain that a chemical compound is a structure in which crystallographically equivalent positions are occupied by chemically identical atoms. In the light of such opinions it is clearly impossible to give a universally acceptable definition of chemical combination. Provided the structure of a substance is known, it is perhaps of little real importance whether it is designated as a chemical compound or not.

Important groups of substances in which the combining proportions may vary, and the valency laws are only approximately obeyed, are the metal sulphides, arsenides, and antimonides. Reference to chemical literature will show that analysts have assigned to the mineral pyrrhotite formulae ranging from Fe_6S_7 to $Fe_{11}S_{12}$. To explain the variable composition, an obvious suggestion is that additional sulphur atoms fit into the interstices of an ideal FeS lattice. This idea cannot be maintained, for crystallographers have shown that there is insufficient space in such a lattice to accommodate sulphur atoms. Two other reasonable explanations suggest themselves. It may be that, in the lattice, sulphur atoms replace iron atoms to a certain extent, or that there are vacant iron positions. That the latter is the true explanation was evident from the work of Hägg and Sücksdorff [1] in 1933. These investigators compared the densities and unit cell measurements of samples of pyrrhotite, and their results are summarized in figure 1, which is taken from their paper. The upper curve indicates the calculated effect on the density of substituting sulphur for iron, while the lower curve shows the calculated effect of withdrawing iron atoms from some of the lattice points. The conclusion is clear. The variation in the composition of pyrrhotite occurs because iron atoms are withdrawn from some of the lattice points. X-ray methods thus solved a problem of profound importance. It is, alas, no longer possible to assure elementary students of chemistry that the stoichiometric compound FeS is formed by heating iron and sulphur together. The term 'defect structure' was proposed in 1936 for such structures, which X-ray investigations have disclosed to be not

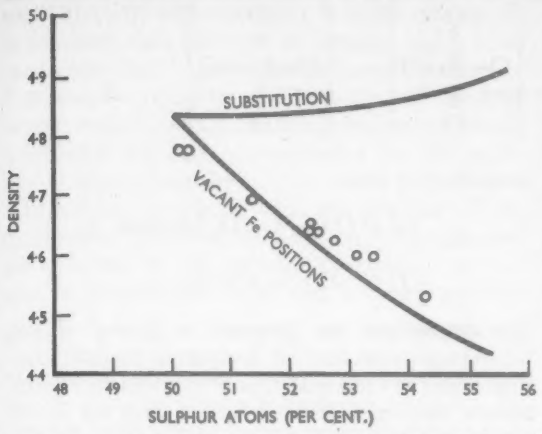


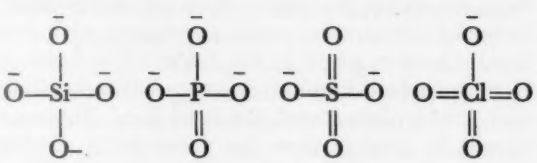
FIGURE 1 – *The circles show the observed variation of density with composition.*

uncommon. In fact, in certain types of compounds they are the rule rather than the exception.

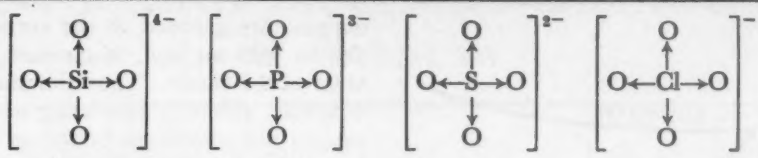
It is reasonable to ask what is the position of the laws of definite and multiple proportions. These laws were formulated at a period when the known chemical compounds were of simpler type. In the light of fuller knowledge it is recognized that the laws are applicable to restricted types of chemical compounds. Many hydrides, phosphides, sulphides, selenides, arsenides, certain oxides and iodides, and some complex compounds are exceptions to the rule [2].

In the realm of inorganic chemistry the study of the arrangement of atoms in solid bodies has enabled chemical problems to be viewed from an entirely new angle. Inorganic chemists at one time postulated a whole series of silicic acids to account for the composition of the mineral silicates. Nowadays it is established that rocks are made up of oxygen atoms cemented together with silicon, aluminium, and a few other metallic atoms. It is well known that the eight common elements—oxygen, silicon, aluminium, iron, magnesium, calcium, sodium, and potassium—account for some 98 per cent. of the earth's solid crust, and the bulk of the crust is oxygen. The distribution of these elements is very interesting. Each silicon atom is surrounded by four oxygen atoms, so that the four oxygens are grouped together at the corners of a tetrahedron and the silicon is situated at the centre. By far the greater part of the aluminium in the earth's crust is distributed similarly to the silicon. Iron, magnesium, and the remainder of the aluminium have a different distribution. Six oxygens are grouped at the corners of an octahedron with an iron, magnesium, or aluminium atom at the centre. Thus aluminium can play a dual role, generally associating tetrahedrally with oxygen but sometimes behaving like the metals iron and magnesium. Finally, the alkali and alkaline earth ions are accommodated in large, often unsymmetrical, holes in the structure. Potash felspar, one of the most important rock-forming minerals, has the empirical formula $KAlSi_3O_8$. The limitations of such chemical formulae in inorganic chemistry are well illustrated by this special case. The felspar is actually composed of silicon and aluminium tetrahedra linked by every corner in every direction, and constituting a three-dimensional lattice-work of tetrahedra. Enmeshed in its interstices are the potassium ions. It is an interesting fact that magnesium and iron are never found in the felspars, and a most convincing explanation of it is available. It is geometrically impossible to fit octahedra into a structure of tetrahedra linked by all their corners. As a consequence, magnesium and iron, which are 6-co-ordinated with oxygen atoms, are excluded from the felspar structure.

In dealing with bonds between oxygen and non-metallic elements, the structure of ions of the type XO_4 is of peculiar interest. The classical formulae showed the central atom with the group valency:



Until recently these formulae had fallen into disuse, principally because of the success with which many compounds could be systematized if the valency group of electrons was assumed to be an octet—a suggestion made by G. N. Lewis in 1916. Assuming that a single bond corresponds to the sharing of two electrons, one from each atom, the classical formulae demand that the central atoms, Si, P, S, and Cl, have valency groups of 8, 10, 12, and 14 electrons respectively. On the octet theory, however, an alternative formulation is possible if it is assumed that the two electrons binding each oxygen atom can be provided by the central atom. This type of bond was named the co-ordinate link and given the symbol →. The atoms Si, P, S, and Cl could then form ions as shown on the following page.



Parachor measurements and stereochemical observations were held to support these formulae. In 1937 L. Pauling and L. O. Brockway [3] pointed out that the bond lengths in the common oxy-acid ions, determined by X-ray analysis of crystals, are much shorter than the single-bond covalent radii for the atoms. The bond lengths in the tetrahedral ions are given below:

	Si—O	*P—O*	*S—O*	*Cl—O*
Observed ..	1·60	1·55	1·51	1·48
Calc. X—O ..	1·83	1.76	1·70	1·65
X=O ..	1·65	1·58	1·53	1·48

What is the significance of this shortening? Pauling interprets the results as indicating that there is a resonance between several possible structures with double bonds holding one or more of the oxygen atoms. In the case of chlorine, the Cl—O distance is that expected for pure double bonds. For formulating these oxy-acid ions Pauling [4] suggests that ordinarily the classical formulae should be used. Obviously the classical formulae are not in entire agreement with the bond distances given in the table. The classical formulae would require resonance between single and double bonds, and the final bond distances should be greater than the value for a double covalent bond. There is evidence, of course, that a co-ordinate link can be shorter than a normal single covalent bond. For example, the N—O distance is 1·43 A—appreciably larger than the nitrogen-oxygen bond length in $(CH_3)_3N\rightarrow O$, which is 1·36 A. It is quite evident that at the present time there is no way of formulating these ions which is free from objection.

The structure of carbon monoxide continues to excite interest, although it has long been a debated problem. Earlier chemists regarded the carbon as bivalent in this oxide and supposed the formula C=O to be entirely satisfactory. Langmuir in 1919 proposed a new formulation, in which carbon would have its octet of electrons. In the early formula it is clear that the carbon has a sextet of electrons. However, by sharing one of the unshared pairs of oxygen electrons the carbon completes its octet:

$$:C::\ddot{O}: \text{ (or } C{=}O\text{) becomes}$$

$$:\bar{C}:::\overset{+}{O}: \text{ (or } \bar{C}{\equiv}\overset{+}{O}\text{).}$$

The arguments put forward in favour of this triple-bond structure of Langmuir include considerations of electrical dipole moment, the interatomic distances, force constant, and the molecular orbital theory. For example, Sidgwick [5] emphasized in 1933 that the minute moment of carbon monoxide can be explained only by supposing that the very unequal sharing of electrons between the carbon and the oxygen is offset by the transference of an electron from the oxygen to the carbon. Pauling in 1939 suggested that the CO molecule must be regarded as a resonance hybrid of the forms

$$\bar{C}{\equiv}\overset{+}{O} \qquad C{=}O \qquad \overset{+}{C}{-}\bar{O}$$

(*a*) (*b*) (*c*)

He brought forward arguments to support the view that the structures (*a*), (*b*), and (*c*) contribute about equally to the normal state of the molecule. The very small value of the electric dipole moment provides evidence that the contribution made by structure (*c*) must be about the same as that of structure (*a*). Structure (*b*) would have no large dipole moment, whereas those of (*a*) and (*c*) are very large. Only if (*a*) and (*c*) contribute about equally would the moment of the molecule be small, in accordance with experiment. Recently, however, it has been argued by L. H. Long and A. D. Walsh [6] that it is quite possible to give a molecular orbital description of the carbon monoxide bond that amounts to an approximate double bond. The great stability of carbon monoxide has frequently been used as an argument against formulating it as C=O. L. H. Long and R. G. W. Norrish [7] in 1946 brought forward a possible reason why CO does not polymerize to O=C=C=O. Their evidence indicates that to excite the CO molecule to a radical with two free valencies would require an excitation energy of more than 75 kcal, and that the energy required to excite two molecules in this manner is greater than the energy normally

associated with a C=C bond. It seems reasonable to conclude that attempts to prepare C_2O_2 have been unsuccessful because this substance is thermodynamically unstable. To sum up, the double-bond formula C=O, while not free from objections, is probably the best representation for this molecule at the present time.

Intimately associated with the problem of the constitution of carbon monoxide is the question of the structure of the metallic carbonyls. At one time it seemed that there was a strong case for writing metallic carbonyls as $M\leftarrow\overset{-}{C}\equiv\overset{+}{O}$ or $\overset{-}{M}—C\equiv\overset{+}{O}$. Here the carbon monoxide provides two electrons to form a co-ordinate link with the metallic atom. In an investigation by the electron diffraction method, Brockway and Cross [8] in 1935 found that the nickel-carbon distance was 1·82 A, whereas the theoretical distance for a double bond is about 1·79 A. This provides support for the view that the nickel-carbon bonds have a large percentage of double-bond character, and this means that the CO must be represented approximately as C=O. However, while the structure of nickel carbonyl in these circumstances is Ni=C=O, there is probably resonance, and the configuration $—\overset{4-}{\underset{|}{Ni}} : C : : : \overset{+}{O}$ must also be taken into consideration. Evidence for both these types of bonding is found in the results obtained by an X-ray analysis of the solid $Fe_2(CO)_9$. Powell and Ewens [9] found that three of the CO groups form bonds $\begin{matrix}Fe\\ \diagdown\\ \quad C=O\\ \diagup\\ Fe\end{matrix}$, as in ketones. The C—O distance in these groups is ca. 1·3 A, comparable with that in ketones and much larger than that in the six remaining CO groups, which is 1·15 A. It is suggested that the bonding here is $\overset{-}{Fe}—C\equiv\overset{+}{O}$. On the data from an electron-diffraction investigation the pentacarbonyl $Fe(CO)_5$ is given a trigonal bipyramidal structure [10]. Here the iron-carbon distances of 1·84 A indicate considerable double-bond character. Finally, the electron-diffraction method applied to the interesting solid carbonyls $Cr(CO)_6$, $Mo(CO)_6$, and $W(CO)_6$ [11], which can be sublimed without decomposition, has indicated that they have a regular octahedral configuration with the metal-carbon distances principally favouring single bonds.

Many of the structural formulae which have been assigned to chemical compounds have in the light of fuller knowledge proved to be quite erroneous. Werner formulated the mineral malachite as

$$\left[Cu\begin{pmatrix}HO\\ \\ HO\end{pmatrix}Cu\right]CO_3.$$

Actually it does not contain a complex ion but consists of a three-dimensional distribution of Cu^{2+}, CO_3^{2-}, and OH^- ions. How dangerous it can be to adopt simple empirical formulae is illustrated by the chloride $CsAuCl_3$. This is not an example of bivalent gold but a complex salt which contains univalent and tervalent gold, with the composition $Cs_2Au'Au'''Cl_6$ [12]. In the solid state phosphorus pentachloride has been shown by X-ray methods to consist of tetrahedral $[PCl_4]^+$ and octahedral $[PCl_6]^-$ ions [13]. A very full determination [14] of the structure of $(NH_4)_3ZnCl_5$ has disclosed that this substance is built up of NH_4^+, Cl^-, and $[ZnCl_4]^{2-}$ ions, and that the true formula is $(NH_4)_2ZnCl_4,NH_4Cl$. As in the case of solid phosphorus pentachloride, the fivefold co-ordination has once again been avoided.

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Rocket exploration

ARTHUR C. CLARKE

Within a generation rocket propulsion has been transformed from the hobby of a few enthusiasts to an accepted field of physical research which has produced results of very great practical importance. In this article Mr Clarke discusses the mathematical basis of rocket propulsion in particular relation to the problem of sending projectiles to great altitudes and—a target which no longer seems impossible of achievement—into space itself.

Although the rocket was invented at least seven hundred years ago, its development as a revolutionary weapon of war and as a high-altitude research instrument is almost entirely a matter of the last twenty years. The first scientific study of the rocket's possibilities was made by the Russian Ziolkovsky at the end of the nineteenth century, but his work was little known outside his own country. The modern era of rocket research may be said to have begun with the American R. H. Goddard (1882–1945) and the Rumanian Hermann Oberth (1894–), whose work put the subject on a secure mathematical basis [1, 2]. Goddard showed that with high-efficiency fuels quite small rockets could attain enormous altitudes, while Oberth investigated the more remote possibility of interplanetary exploration. His work was directly responsible for inspiring German rocket research in the 1920's, and from that research in due course came the numerous rocket weapons developed in the later stages of the recent war. Most of the features of the modern liquid-fuel rocket had been foreseen by Oberth twenty years ago.

The rocket owes its outstanding properties to the fact that it is the simplest, and potentially the most efficient, of all heat engines. There is no obvious limit to the size of rocket motor that can be built—for example, the V2 developed over 600,000 h.p., and much larger units are under investigation. Moreover, since it is a pure reaction device and carries its own fuel and oxidizer, it is quite independent of a surrounding medium. The rocket is thus the only known form of propulsion which will operate in airless space, where it is in fact more efficient than in the atmosphere.

The problem of reaching very high altitudes is essentially a ballistic one, since the rocket may be treated as a mere projectile for most of its flight. For ordinary altitudes and velocities of projection the familiar law $h = v^2/2g$ is applicable (if air resistance is neglected), but this parabolic relationship assumes g to be constant throughout the trajectory of the projectile, whereas when the initial velocity exceeds 3 km/sec, the projectile reaches altitudes where gravity is appreciably weakened. Figure 1 shows the operation of the constant-gravity law, and of the correct law allowing for reduction of g with distance. It will be seen that the altitude curve is rising very rapidly at values of 10 km/sec, and it actually reaches infinity at the 'velocity of escape,' 11·2 km/sec.

So far, the greatest terminal velocities attained by rockets are about 1·5 km/sec, and the maximum altitudes are in the region of 180 km. These results were achieved by V2, a purely military machine, and much better performances will be possible with rockets built specifically for high-altitude research. Details have recently been published of a sounding rocket (*Neptune*) now under construction for the U.S. Navy, and because they show very clearly the main characteristics of such machines the performance curves are reproduced in figure 2.

The rocket burns its fuel (in this case alcohol and liquid oxygen) in 75 seconds, during which time it rises vertically for 60 km and reaches a velocity of 2·5 km/sec. This is sufficient to enable it to coast to a maximum altitude of 400 km, the complete upward flight taking 335 seconds. *Neptune* (which should be in use by the end of 1948) is designed to carry 50 kg of instruments to the 400 km level, but it can also carry loads of a metric ton to 140 km.

The development of such machines opens up quite new fields in scientific research, and notable results have already been obtained with modified V2's by American workers at White Sands, New Mexico. For the first time it has been possible to secure direct readings of temperature and pressure at heights well into the ionosphere, and recently the first spectrograms were obtained of the sun's ultra-violet radiation, which does not penetrate the atmosphere. Techniques have been developed

for transmitting observations continuously to receivers on the ground while the rocket is in flight, and it is now possible to retrieve instruments undamaged after their fall back to earth.

Meteorology, physics, and astronomy—to mention only three sciences—will benefit greatly when regular programmes of rocket sounding begin. Quite apart from this, it must be confessed that such research has an excitement—one might even say a glamour—which is met elsewhere only in the more spectacular branches of atomic physics. The high-altitude rocket has given us our first real freedom of movement in three dimensions, even if at the moment that freedom is by proxy only.

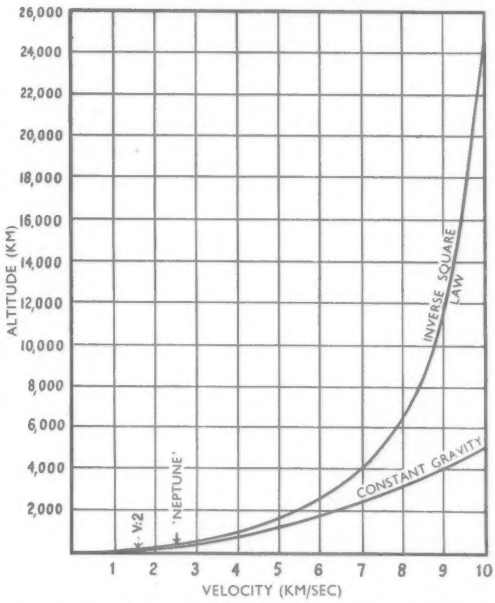

FIGURE 1 – *Relationship between velocity of projection and altitude,* (a) *assuming that the gravitational field is constant,* (b) *assuming the reduction of the gravitational field according to the inverse square law.*

The velocity reached by a rocket—and hence its performance—is determined by two factors: (1) the velocity of the jet or exhaust, and (2) the mass-ratio, which is the ratio between the rocket's initial weight and its final weight after combustion of fuel. If v is the jet velocity and R the mass-ratio, then in the absence of any other forces the final velocity attained by the rocket is given by the equation:

$$V = v \log_e R.$$

However, for a rocket fired vertically from the earth, gravity and air resistance come into play,

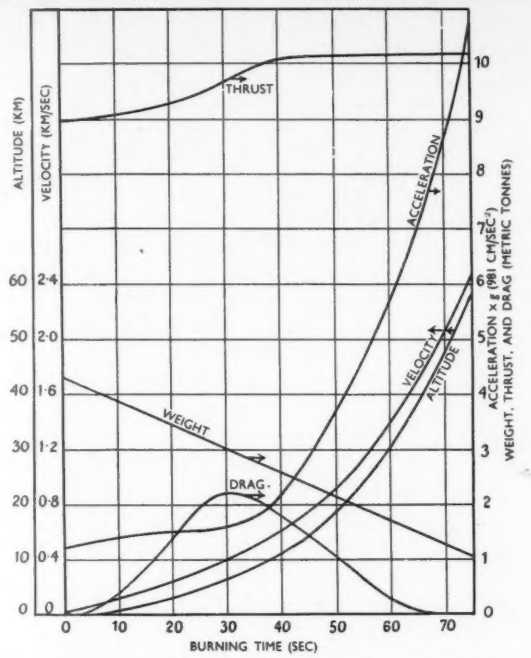

FIGURE 2 – *Calculated performance curves for the U.S. Navy's high-altitude sounding rocket* Neptune.

and the final velocity at 'all-burnt' is reduced to:

$$V = v \log_e R - gt - F(V,h),$$

where t is the time of combustion, and $F(V,h)$ is a

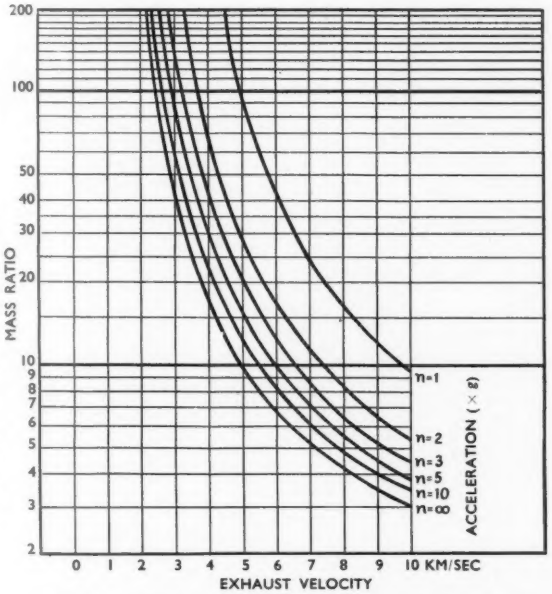

FIGURE 3 – *Relationship between exhaust velocity and mass-ratio for rockets of different acceleration.*

FIGURE 4 – *Photograph of the earth taken from an altitude of* 100 *miles by means of a V2 rocket launched in New Mexico. An area of more than* 200,000 *square miles is covered. The curvature of the earth is clearly seen.*

term depending in a complex manner on the rocket's shape, altitude, and velocity. Fortunately, as the drag curve in figure 2 shows, air resistance falls practically to zero as the rocket's speed and altitude increase, and the loss in performance due to this cause is not more than 10–20 per cent. It could be reduced substantially by mountain-top launching, which might be worth while in some applications. The gravitational loss gt can also be kept low if high accelerations and hence short periods of burning are used: *Neptune's* final acceleration will be over 10g.

Of the two variables v and R, the former is the more critical because, as it is the logarithm of R that enters into the expression, variations in the value of R have a smaller effect than similar variations in v. Exhaust velocities of 2·5 km/sec have been attained with present-day motors and with fuels of the alcohol-oxygen type. Very much more powerful fuels exist, but it is not yet possible to use them owing to the high temperatures developed. Even present-day fuels have to be used under dilution to restrict chamber temperatures to less than 3,000° K. When these limitations are overcome, jet velocities of perhaps 5 km/sec may be ultimately attained. There is a tremendous field of research here for the chemist and the metallurgist—how large may perhaps be judged by the fact that during the war over 6,000 rocket fuels were tested at one German establishment alone.

The mass-ratio R is limited by purely engineering considerations, chiefly the dead-weight of motor and fuel tanks. For V2 it was about 3·5; for *Neptune*, as figure 2 shows, it will be just over 4. Possibly twice this ratio may ultimately be attained with a single-stage rocket. Taking a figure of 7, we see that it should eventually be possible to build rockets capable of reaching speeds of $5 \times \log 7$ or 10 km/sec. Allowing for a loss of 2 km/sec against air resistance and gravity, such machines would be able to reach altitudes of 6,000 km.

Such an altitude, though very considerable by any ordinary standards, is only one radius of the earth. To exceed this, and in particular to reach the velocity of escape, is a much more difficult but not an insuperable problem. The possibility of landing an instrument-carrying rocket on the moon is one that has engaged much attention recently. In particular we might mention Chapman's proposal [3] that a magnetometer be sent to the moon to test Blackett's ideas concerning the magnetic field of rotating bodies.

As previously mentioned, the escape from the earth requires a velocity at 'all-burnt' of 11·2 km/sec, and figure 3 shows what this implies in terms of mass-ratio and exhaust-velocity for rockets of different accelerations. The curves show that with fuels and motors in the 3–4 km/sec range, mass-ratios of up to 100 will be needed to reach escape velocity. At first sight it might seem quite impossible to build a rocket weighing say 100 tons, of which 99 tons were fuel while the remaining ton comprised the total weight of structure, motors, fuel tanks, and payload. The difficulty may, however, be circumvented by the device known as the step or multiple rocket.

When a rocket is used to carry a smaller machine to a great height and then dropped off, the upper component will be travelling at a high speed with all its fuel unused. This process may, in theory, be repeated for any number of steps, so that one might have a rocket with an initial mass of hundreds or even thousands of tons, and a final mass of only two or three tons. In this way it would be possible, at least in principle, to design machines capable of reaching the moon or planets, even with chemical fuels. Recent studies indicate that an initial weight of perhaps 50 metric tons would be necessary to land a payload of 50 kg on the moon, but the figures are very sensitive to changes in the assumed exhaust velocity.

It is of interest to note that the step-rocket is no merely theoretical device. In the closing months of the war, about twenty missiles known as *Rheinbote* were fired into Antwerp from a range of about 150 km. Very little information has been released concerning this weapon, but it is known to have been a four-step rocket.

Summarizing these results, we may say that once purely engineering and development problems have been overcome it will be possible to send research missiles into space for immense distances, and, moreover, to receive information from them while they are in flight. One of the most interesting possibilities which this opens up is that of obtaining photographs and television pictures of the moon's hidden face. A less spectacular but perhaps more useful feat would be the steering of rockets into permanent orbits around the earth, from which they could broadcast instrument readings to ground stations for long periods of time. A body travelling horizontally at 8 km/sec just outside the atmosphere would continue to circle the earth for ever, like an artificial satellite, and by a suitable choice of speed a body could be made to move in an orbit at any desired altitude

and with a period of from 1½ hours upwards. The 24-hour orbit, with a radius of 42,000 km, is one which may have important applications, since a body placed in it would always remain fixed over the same spot on the earth. This indicates the remarkable possibility of having scientific instruments permanently fixed in the sky, in apparent defiance of the law of gravitation. It has been suggested that radio repeater stations in such orbits may provide the ultimate solution to the long-distance television relay problem [4].

Although these things would have seemed quite fantastic a few years ago, they are now distinct possibilities of the next decade, for they require no new fundamental knowledge for their achievement. They will open up new fields of science and may well transform much of astronomy and physics. But even that may be merely incidental, for they point the way, clearly and unmistakably, to the ultimate achievement of interplanetary travel—perhaps the most daring dream ever conceived by the minds of men.

To land human beings on the moon, and to ensure their safe return to earth, is obviously a far more difficult task than the mere projection of a guided missile into space. Theoretical studies indicate that it might just be done with step-rockets burning chemical fuels, but the difficulties and the expense would be enormous, since every kilogram taken on the round journey would require at least a ton of fuel at the take-off.

It is now generally agreed that true space-ships capable of reaching other planets will not be practicable until atomic energy is harnessed for rocket propulsion—and of all the applications of atomic energy, this appears to be the most difficult. There is, of course, no doubt that nuclear reactions could produce ample energy for any conceivable interplanetary journey. To quote a striking example, the few kilograms of matter in the Bikini bombs liberated enough energy to take a thousand tons to the moon and back.

The only schemes so far put forward for atomically driven rockets [5, 6] have envisaged the use of very high temperature chain-reactors accelerating gas streams through propulsive nozzles. For a given combustion-chamber temperature, the velocity of the gas from a rocket varies approximately inversely as the square root of its molecular weight. The impulse given to the rocket by the gas jet depends on the momentum of the jet, i.e. its mass × velocity; thus for a given mass, the gas with lowest molecular weight has the highest exit velocity and so generates the highest momentum. In the chemical rocket the exhaust gases are usually carbon dioxide and steam, but an atomic rocket could use hydrogen or helium as working fluids, since no actual combustion need take place. It could thus produce exhaust velocities three or four times as great at the same chamber temperature as before, with an enormous decrease in fuel requirements. The technical problems involved are exceedingly formidable, but work is proceeding along these lines in America under the NEPA ('Nuclear Energy—Propulsion of Aircraft') project, and perhaps elsewhere. As a glance at figure 3 shows, an increase of exhaust velocity into the 10 km/sec region would reduce the mass-ratios needed for the escape from earth to a value which can be achieved with a single-stage machine of present-day design. Interplanetary return journeys would still require the use of fairly large step-rockets, but the initial weights required would be hundreds instead of scores of thousands of tons.

This is not the place to discuss the possible consequences of interplanetary travel: there have been perhaps too many treatments of the subject elsewhere. It should, however, be patent to all who consider the matter dispassionately that the crossing of interplanetary space will mark one of the great turning-points in human history, for it will end man's physical isolation from the rest of the universe.

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Plant tissue culture

R. J. GAUTHERET

Methods of growing animal tissues in isolated cultures were perfected more than thirty-five years ago, but plant tissue culture proved more difficult, and complete success was not achieved until shortly before the outbreak of the last war. In this article are described the methods used in plant tissue culture; the use of the cultures in studying problems of morphogenesis, pathology, and physiology; and their application in research upon plant galls.

HISTORICAL

It is now nearly three centuries since the first attempts at structural analysis of organisms led to the discovery of the cell. From subsequent observations on animals and plants, biologists framed the cell theory, according to which the cell represents both a morphological and a physiological unit. Later, the histologists of the classical period established the universality of the cell structure and succeeded in confirming the first point of the theory. They failed, however, to verify the second point, for since they studied only dead organisms cut into thin sections they were unable to demonstrate the physiological individuality of the cell.

In order to establish this point it was, in fact, necessary to show that cells are capable of surviving and multiplying outside the organism. The botanist Haberlandt was the first to realize the importance of an experiment on these lines. As early as 1902 he tried to cultivate various types of plant cells, both epidermal and parenchymatous, but he failed completely, because the elements he used had matured and were too strongly differentiated to multiply *in vitro*.

It was not until 1922 that Robbins in America saw the way which was to lead to success. He assumed that cultivation of plant tissues could succeed only by using cells normally capable of division, i.e. meristematic cells. Some of these cells are located in the tips of plant shoots and roots, where they form small, compact masses called growing points: it was these meristems which Robbins began to cultivate. He isolated root tips and placed them in suitable nutrient media. They grew rapidly and branched, but their proliferation ceased at the end of a few months. In 1934 White resumed these experiments and succeeded for the first time in obtaining unlimited development of isolated roots (figure 1). However, these root cultures were cultures of organs possessing a definite form and structure, and there could be no hope of obtaining a true tissue culture by this method.

In an attempt to achieve such a true culture the author tried as early as 1934 to cultivate a type of meristem different from that used by Robbins and White. The type of meristem chosen was the cambium, which forms a cylindrical zone inside stems and roots between the phloem and the wood. It is particularly well developed in trees, and its active development ensures growth in diameter. When attempting to cultivate fragments of cambial tissue, it was found that they expanded and produced unorganized parenchymatous masses. The proliferation of such cultures ceased at the end of a few months, but the attempt had nevertheless given promising results; it led to further research, which culminated in the production of true tissue cultures capable of unlimited development. This result was announced by White on 30th December, 1938, by the author on 9th January, 1939, and lastly by Nobécourt on 20th February, 1939.

GENERAL CHARACTERISTICS OF PLANT TISSUE CULTURE

An experiment on plant tissue culture usually begins by placing a fragment of a slightly differentiated organ on the surface of an appropriate nutrient medium, the general composition of which is dealt with below. If a favourable material is used, proliferation starts at once and parenchymatous calluses are seen to form. In this way shreds of tree-bark, pieces of herbaceous shoots or creepers (figure 2), slices of fleshy organs, etc., can be cultivated successfully. 'Explants' proliferate very intensively at first, but proliferation slows down after a few months, then ceases, and finally the cells die.

In order to prolong the activity of the cultures they must be planted out, that is, a fragment of tissue from a rapidly growing region of the original

explant is transferred to a new medium where it can continue its development. This fragment then grows in all directions and is gradually transformed into a more or less rounded mass. At the end of one to two months, according to the species, planting out is repeated, and so on. It is observed that tissue colonies which have been planted out several times have a very different appearance from the corresponding normal tissues, but they have, nevertheless, an entirely characteristic morphology which is the same for a given species. Thus colonies of carrot tissues have a nippled surface with parenchymatous nodules almost isolated from one another (figure 3). Cultures of vine tissues produce very curious digitations on their surface (figure 4), which bear a vague resemblance to the plasmodial veins of certain myxomycetes. On the other hand, the colonies produced by *Scorzonera*, or by Jerusalem artichoke, and others, are almost smooth.

This method, the principle of which is briefly indicated above, has already made it possible to cultivate tissues of numerous plants, all dicotyledonous, and we have actually isolated nearly thirty different strains (hawthorn, willow, vine, Virginia creeper, tobacco, snapdragon, carrot, Jerusalem artichoke, and some other species, are almost more than ten years old).

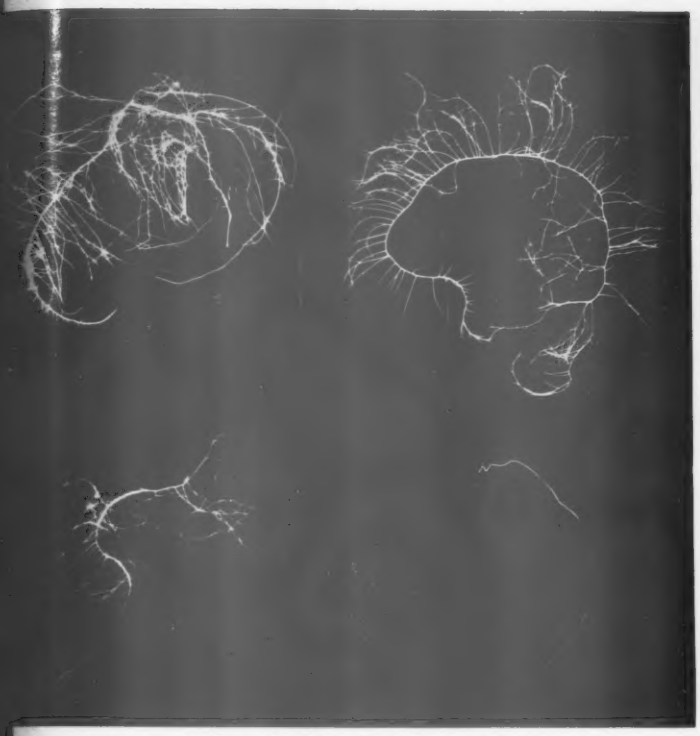
These strains derive from the proliferation of normal plant tissues, but it has also been possible to cultivate pathological tissues, especially gall tissues. White, to whom we owe the first work on this kind of tissue, isolated a strain from genetic galls spontaneously produced by certain tobacco hybrids. Collaborating with Braun, he succeeded later in cultivating tissues of crown gall from sunflower and *Vinca*. It should further be noted that Morel also produced crown gall tissues, proceeding from galls in tobacco, *Abutilon*, and other plants. In the United States, Black succeeded in developing tissues of very peculiar galls produced by certain viruses. Finally, we provoked a remarkable gall process by subjecting normal tissue cultures to prolonged treatment with heteroauxins. After treatment the cultures behaved like typical gall cultures and, in particular, presented the principal morphological and physiological properties of crown gall tissue cultures.

For the purpose of establishing as close a comparison as possible between normal tissues and gall tissues, research workers have endeavoured to obtain cultures of both kinds of tissue from the same plant, in some cases with success; for instance, from Jerusalem artichoke we isolated a strain of normal tissue and a strain of crown gall. Morel also obtained these two types of culture for vine and tobacco. For *Scorzonera* we even produced three kinds of cultures: cultures of normal tissues, of crown gall tissues, and of 'chemical galls' produced by the prolonged action of heteroauxin. The comparative study of these three types of cultures should enable us shortly to solve various problems in connection with gall phenomena in plants.

To conclude this examination of the general characteristics of tissue cultures, we may point out that research workers have not confined their attention to the external morphology of tissue colonies but have also examined their anatomical structure. These studies revealed the existence of two types of organization. In a few cases, e.g. willow or certain vine strains, the colonies are entirely parenchymatous (figure 5) and therefore represent pure cultures of a single type of cell; but more often the structure is heterogeneous, and in such cases they are composed of a fundamental parenchymatous mass (figures 6 and 7), permeated by more or less well-defined vascular strands in which can be seen xylem elements and sieve tubes associated with cambium cells. Such colonies must be regarded as cultures of cambium and its derived tissues.

NUTRIENT REQUIREMENTS OF PLANT TISSUE CULTURES

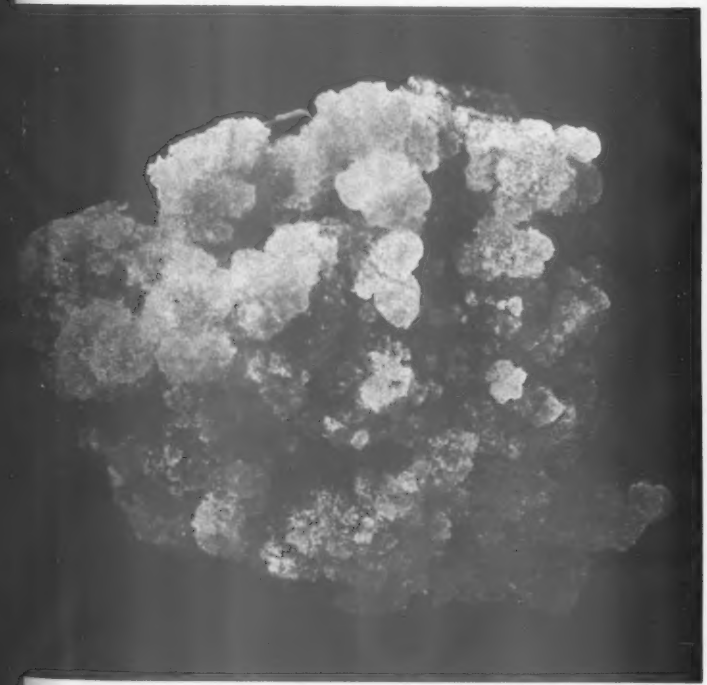
Culture media permitting the proliferation of plant tissues always contain water, agar as a solidifying agent, mineral salts, an organic source of carbon (glucose or sucrose), and very often traces of some organic substances acting as growth factors (vitamin B_1, glycocoll, indoleacetic acid, cystine, biotin, pantothenic acid, etc.). Repeated trials have established that all tissues have approximately the same requirements of mineral salts and sugars, but their requirements of growth factors differ according to the species. Certain tissues, such as Jerusalem artichoke, Virginia creeper, and others, cannot develop if the medium contains no heteroauxin (figure 8) but show very active proliferation if it contains traces of indoleacetic acid or some other heteroauxin (figure 9). Other tissues, especially willow and hawthorn, are more specific in their requirements; here a culture can be obtained only if the medium contains the three following growth factors: indoleacetic acid, biotin, and pantothenic acid. Others again, e.g. carrot and chicory, can be cultivated on a medium containing only mineral salts and



URE 1 – *Isolated root cultures (White). These photographs show isolated roots d from strains which had been transferred several times.*

eft, Petunia. *Top right*, Trifolium repens.
m left, Nicotiana Langsdorffii. *Bottom right*, Daucus carota.

FIGURE 2 – *Fragment of vine shoot after two months' culture. Note that it has developed to form a large protuberance.* (×5)



RE 3 – *Carrot tissue culture, two months old, derived from a ten-year-old strain erred* 58 *times. The colony is seen to present a mamillate surface with paren- ous nodules almost isolated from each other.* (×6·5)

FIGURE 4 – *Vine tissue culture two months old, derived from a three-year-old strain. The surface of the colony has produced digitations resembling the plasmodial veins of certain myxomycetes.* (×18) *(Vincent, photo by Morel)*

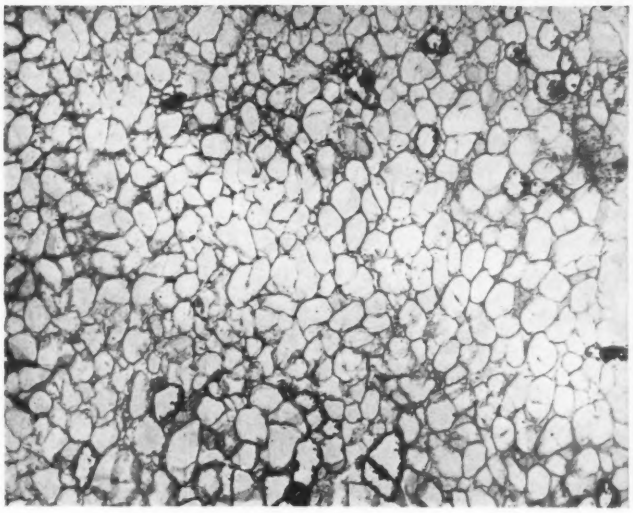


FIGURE 5 – *Section of a vine parenchyma culture. The tissue is seen to consist solely of parenchymatous elements. The black cells are cells containing tannin which has been precipitated by the fixative.* (×60)

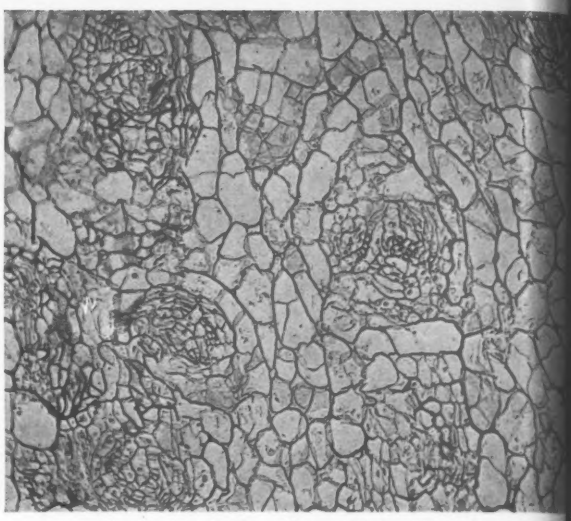


FIGURE 6 – *Section of a Jerusalem artichoke tissue culture, derived a seven-year-old strain transferred 41 times. Note that the colo composed of a parenchyma containing cribrovascular nodules.* (

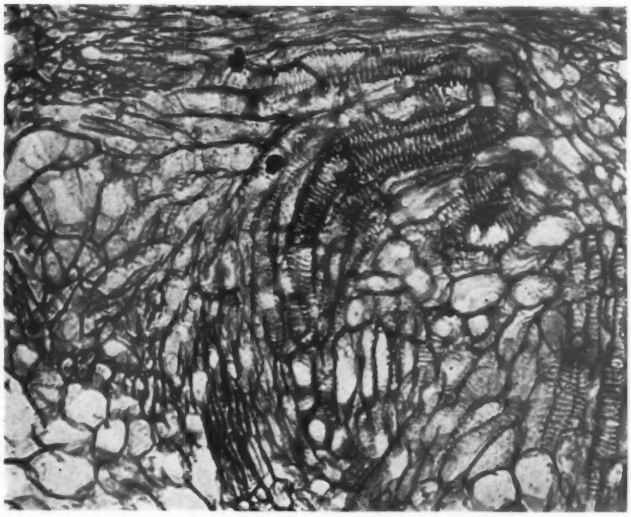


FIGURE 7 – *Vascular formations developed in a chicory tissue culture. Lignified elements can be distinguished surrounded by sieve tube areas. Between these two tissues can also be seen rudimentary cambium.* (×300)

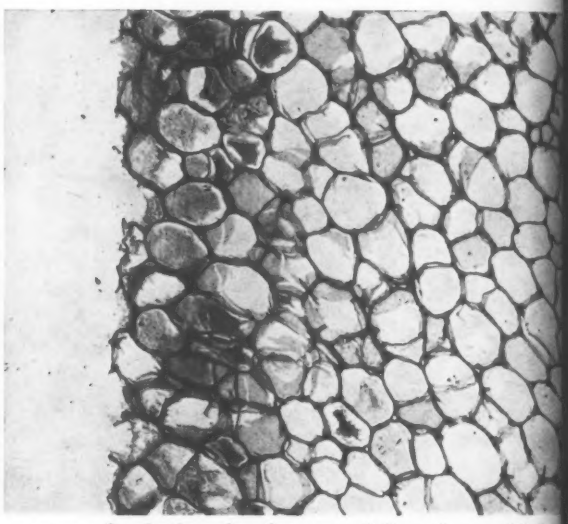


FIGURE 8 – *Section of a fragment of Jerusalem artichoke cultivated for two months in a medium containing no hetero The cells have not multiplied.* (×90)

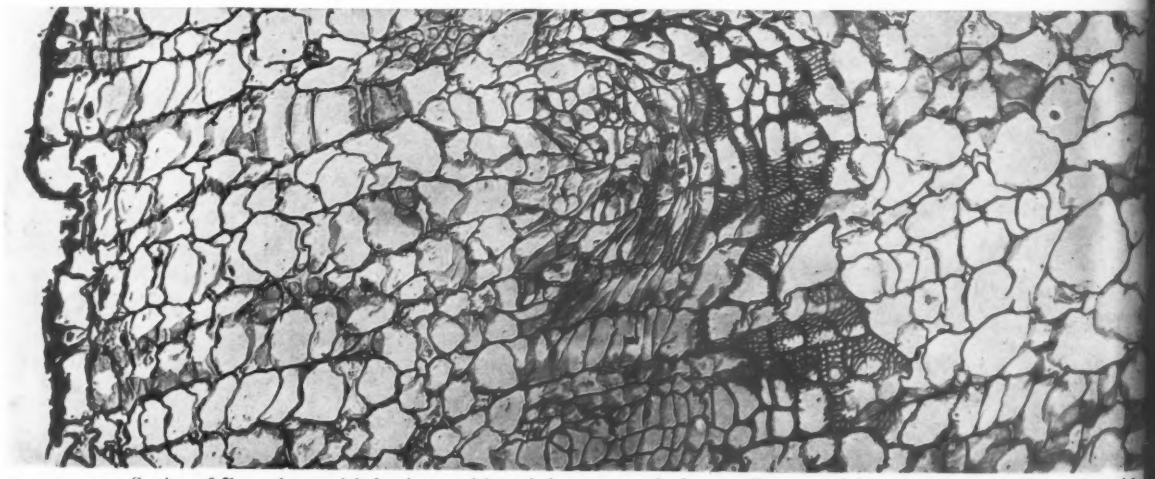


FIGURE 9 – *Section of Jerusalem artichoke tissue cultivated for two months in a medium containing 0·0001 gm indoleacetic acid litre. The surface has proliferated to form a sort of parenchyma within which are vascular elements composed of a phloem island a lignified cell island separated by a meristematic zone.* (×160)

glucose,[1] but the presence of growth factors is likely to intensify proliferation. Finally, it should be noted that gall tissues, whatever their origin (genetic, bacterial, virus, or chemical), can be cultivated in the absence of heteroauxin and are almost insensitive to the formative stimulant action of substances of this type.

Recent experiments by Skoog and de Ropp support the assumption that this very peculiar behaviour of gall tissues is due to the fact that they produce a substantial quantity of indoleacetic acid.

PLANT TISSUE CULTURE AND MORPHOGENESIS

The study of tissue cultures makes it possible to analyse the conditions of development of the plant organs, e.g. the determination of rhizogenetic processes has been defined by means of the reaction of heteroauxins on tissues cultivated *in vitro*, and the factors influencing the initiation of bud-formation have been investigated by the use of tissue cultures. During research on tobacco tissue cultures, White found that the production of leaf primordia is facilitated by immersing the colonies in the nutrient medium. This result was confirmed by Skoog, who also examined the effects of light, temperature, and heteroauxins on bud-formation, and investigated the conditions under which organs may produce undifferentiated colonies or vice versa. Bud-determination has also been studied by the author, who used elm cambial tissue.

With regard to more particular problems of morphogenesis, tissue culture has enabled us to analyse the histogenetic processes. Thus anatomical observations of tissue cultures of carrot, Jerusalem artichoke, chicory, etc., have shown that the meristem zones always appear at the boundary separating two tissues of different kinds. These studies also made it possible to analyse the method of development of cribrovascular strands appearing inside originally homogeneous tissues. Some remarkable experiments carried out by Camus have shown that buds grafted *in vitro* have a histogenetic action involving de-differentiation processes followed by differentiation and organization phenomena.

Lastly, Buvat discovered the morphological mechanism of the de-differentiation of tissues cultivated *in vitro*, by cytological analysis of these processes. Thanks to the technique of tissue culture, precise new knowledge has been gained of the phenomena of polarity. In particular, numerous experiments on fragments of carrot and chicory roots have shown that polar plant development is the result of a hormonal mechanism, characterized by the conveyance of a morphogenetic substance from the leaf towards the root.

PLANT TISSUE CULTURES AND PHYSIOLOGY

The original aim of the workers who developed the first cultures *in vitro* was to determine the chemical factors in cellular multiplication. The results obtained with isolated roots by Robbins, White, and Bonner have long since established the fact that proliferation of root meristems requires mineral salts, a simple sugar (glucose or sucrose), and some other organic substances—e.g. glycocoll, vitamin B_1, vitamin B_6, and nicotinic acid—the nature of which varies according to the species.

Further research on tissue cultures, however, led to quite different results. Tissues cultivated *in vitro* can in fact proliferate in the absence of the substances just named, but in certain cases other factors must be provided. These have been mentioned previously—heteroauxin, biotin, pantothenic acid.

The use of tissue culture thus represents an excellent method of studying cell nutrition. It should make it possible to assess the value of all substances (cystine, traumatic acid, etc.) which have been considered, without proof, as stimulants of proliferation. In our opinion the highly obscure problem of neoformative substances, such as caulocaline and rhizocaline, may be solved by this method.

PLANT TISSUE CULTURES AND PATHOLOGY

We shall conclude this account with a very brief indication of the results obtained in plant pathology by means of tissue culture.

The first work in this field was done by White. In 1934 he tried to use isolated tomato roots to cultivate virus proteins, which, as we know, are incapable of growth in inert media. Segrétain reached similar results by using tissue cultures. Recently Morel extended this method to the culture of certain obligate parasites such as downy mildew and oidium of the vine. Tissue culture has also furnished important results in the study of galls, especially crown gall.

[1] In order to prevent the interference of impurities likely to contain growth factors, it is necessary in certain experiments to abandon the use of agar for solidifying the nutrient media and cotton wool for plugging the culture vessels. Glass fibre soaked in a nutrient solution is used as solid support, and tinfoil caps are employed to close the vessels.

Book reviews

HISTORY OF THE PHYSICAL SCIENCES

The Growth of Physical Science, *by the late Sir James Jeans. Pp. x + 364, with a frontispiece and 13 plates. University Press, Cambridge.* 1947. 12*s.* 6*d. net.*

Sir James Jeans was not only a scientist of the first rank but possessed the rare and enviable gift of interpreting science to the layman. His popular books on cosmology had, and still have, a very wide circulation, and his public lectures always drew large audiences. The present book, which describes the main lines of advance of physical science (including astronomy and mathematics), will doubtless prove equally successful among uncritical readers, for it possesses all the lucidity and charm of style of its predecessors. The historian of science, however, will not be able to pass a wholly favourable judgment upon it: The broad outlines are drawn with all Jeans' accustomed skill, and in the fields with which he was particularly familiar the details are accurate and well selected. There are, however, far too many minor errors in the book as a whole. For example, it is implied that alchemy ceased to be practised in Alexandria after Diocletian's decree against it; a celebrated Muslim mathematician is described as al-Kirismi instead of al-Khwarizmi; the Arabs are correctly stated to have taken their numerals from India, but no mention is made of their fundamentally important addition of the cipher; Mayow's work on combustion is overrated; and there are numerous misprints such as Mikola for Nikola (Copernicus), Humphrey for Humphry (Davy), Hayyam for Hayyan (Jabir), Canizzaro for Cannizzaro, and Amerigo for Amedeo (Avogadro). These and similar errors, though each is small in itself, are in fact so numerous as to form a serious blemish on what might have been an excellent book. They should be corrected in future editions or impressions.

PARTICLE TRACKS

Nuclear Physics in Photographs; tracks of charged particles in photographic emulsions, *by C. F. Powell and G. P. S. Occhialini. Pp. viii + 154, with 50 plates. Oxford University Press.* 1947. 18*s. net.*

Nuclear physics has become so much a matter of elaborate and expensive engineering—cyclotrons, betatrons, and the like—that it is refreshing to see that there is one important line of work which uses nothing more abstruse than a photographic plate and a microscope. It is true that the plates now used are of a rather special type, but the earliest work was done with quite ordinary ones. It has been known for a long time that a photographic plate records the passage of certain ionizing particles, such as the alpha rays ejected from radium, and that under suitable conditions and magnification the track of a single particle can be seen as a closely spaced row of dots in the photographic emulsion. Attention was directed to the method shortly before the war, when two Viennese ladies, Drs Blau and Wambacher, discovered that plates left for some time near the top of a mountain showed after development remarkable 'stars,' consisting of from two to twenty tracks diverging from a point and apparently representing the paths of fragments of an atom smashed by a cosmic ray. Dr Powell and his co-workers at Bristol have made a prolonged study of these effects, and have also applied the method to study the tracks produced in the emulsion under the action of other kinds of radiation.

The present work is, as regards its text, a short and clearly written account of the elementary principles of nuclear physics, each chapter of which is illustrated by a number of plates showing tracks of particles which exemplify the principles in question. These plates are truly magnificent and show the great progress that has been made in the technique, largely owing to the excellent work done by the research staff of Ilford's in preparing improved photographic emulsions. These pictures make the processes of nuclear physics extraordinarily vivid. In a great many ways the method is similar to that of the Wilson Chamber, but it has an advantage in recording rare events because the plate can store up all that happens to it over a period of weeks.

Very recently the work of Powell has made it nearly certain that there is more than one kind of 'heavy electron' or meson, the first of which was discovered in cosmic rays, shortly before the war, by Anderson. It has also become very likely that there is also an uncharged meson, a sort of poor relation of the neutron. The number of 'elementary' particles is thus rising fast, and the old simplicity of proton and electron has gone. But this increasing complexity is a healthy sign: it is the indication that a new synthesis is not far away.

G. P. THOMSON

PALAEOBOTANY

An Introduction to Palaeobotany, *by Chester A. Arnold. Pp. 431, with 187 figures. McGraw-Hill Publications, London.* 1947. 27*s.* 6*d. net.*

Books on fossil botany have never been abundant. During the past decade they have, in fact, been rather scarce, as some of the major texts have been out of print. It is to make good this deficiency that Professor Arnold of the University of Michigan has prepared this volume. His aim was to produce an up-to-date, concise, yet sufficiently comprehensive book for the use of students, and thereby to sustain and promote an interest in palaeobotany and to convey some idea of the importance and value of this subject to both botanists and geologists. It may be said at once that the author has succeeded admirably in this task: he has written a book which will be welcome wherever a lively interest in the evolution of plants is maintained.

The book contains much information of the kind that an advanced student will particularly want to know: the techniques by which fossils may be studied, and how the data which they yield shed light on the evolution of the major classes of plants. In some instances support is lent to the classical views; in others, new views are propounded, or a suspension of judgment is advocated until our knowledge is further extended. The author is enthusiastic about his subject but cautious in the interpretation of his material.

Certain chapters centre around major groups of plants, while other chapters deal with special topics such as the geological sequence of plants. Professor Arnold, though not pessimistic, treads warily where phylogenetic reconstructions are concerned. 'As yet,' he says, 'we have not been able to trace the phylogenetic history of a single group of modern plants from its beginning to the present.' This is very true, though perhaps not always realized.

C. W. WARDLAW

Notes on contributors

LINUS PAULING,
B.S., M.A., Ph.D., D.Sc.,

Was born in Oregon in 1901 and was educated there (Oregon State Agricultural College) and in California (California Institute of Technology). His main field of work is chemistry; he was a teacher of quantitative analysis for one year, and is at present in charge of general chemistry at the California Institute of Technology, where he is Professor of Chemistry and chairman of the Division of Chemistry and Chemical Engineering. In 1926 and 1927 he studied in the field of theoretical physics at the universities of Munich, Zürich, and Copenhagen. His first field of research dealt with the structure of crystals, and culminated in his formulation of a general set of principles underlying the structure of complex crystals, including the silicates, and of systems of ionic and covalent radii. He also carried out many applications of quantum mechanics to problems of molecular structure, and in 1939 published his book, *The Nature of the Chemical Bond*, in which his work on hybridized orbitals, partial ionic character of bonds, resonance and electronic structure of molecules, and related topics is summarized. His fourth book, published in 1947, is a textbook of general chemistry. In 1933 he began work on the structure of haemoglobin and other proteins, and in 1940 he published a paper on the structure of antibodies and the nature of serological reactions. Since 1940 he and his collaborators have carried out an extensive series of experimental investigations in the field of immunochemistry, designed to throw further light on this complex subject.

Professor Pauling is at present George Eastman Visiting Professor at Oxford. He recently received the Davy Medal of the Royal Society, and has also received the American Chemical Society Award in Pure Chemistry, the William H. Nichols Medal, the J. Willard Gibbs Medal, and the Theodore W. Richards Medal.

In 1947 he was awarded Honorary D.Sc. degrees by the universities of Cambridge and London, and he has also received honorary degrees from several American universities.

J. R. PARTINGTON,
M.B.E., D.Sc.

Born in 1886 in Bolton, Lancashire, he is a North Countryman of English as well as Scottish origins. He graduated at Manchester University, where he studied under H. B. Dixon, and later carried out post-graduate work in physical chemistry and thermodynamics in the University of Berlin under Nernst and Planck. He returned to Manchester as a member of the staff of the University Chemical Department, and from 1914 to 1919 served in the Army and the Ministry of Munitions. Since 1919 he has been Professor of Chemistry in the University of London (Queen Mary College). He has published numerous papers and books on inorganic and physical chemistry, thermodynamics, the alkali industry, the specific heats of gases, and chemical mathematics. He has a wide knowledge of the history of chemistry, to which subject he has extensively contributed. His *Origins and Development of Applied Chemistry* covered the vast field of the hitherto unexplored prehistory of chemistry.

B. K. JOHNSON,
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Began his education at the Langton School, Canterbury, whence he obtained a scholarship to Christ's Hospital. He was for some years with Messrs. Adam Hilger Limited, London. He lectures in the Physics Department of the Imperial College of Science and Technology, and is a Recognized Lecturer of the University of London. He has specialized in optical science, and has carried out research on optical design and lens computation, and on short-wave microscopy.

WILLIAM WARDLAW,
D.Sc., F.R.I.C.,

Was born in 1892 and was educated at Rutherford College, Newcastle-on-Tyne, and the University of Durham. In 1937, after being senior lecturer in inorganic chemistry in the University of Birmingham, he was appointed Professor of Physical Chemistry in the University of London (Birkbeck College). Since 1939 he has been an honorary secretary of The Chemical Society and was senior secretary during the recent centenary celebrations. He is well known to many British scientists through his work with the Technical and Scientific Register of the Ministry of Labour and National Service. He has published numerous papers on co-ordination compounds.

A. C. CLARKE

Was born in 1917, and before the recent war was an Exchequer auditor in the Civil Service. During the war he was a flight-lieutenant in the R.A.F., and was in charge of the first Ground Controlled Approach Radar prototype during development trials in the United Kingdom with Radiation Laboratory scientists. He was later responsible for the building and maintenance of G.C.A. training equipment and for the surveying of airfields for G.C.A. installations. He resigned from the Civil Service on demobilization, and is now at King's College, London. He has been a member of the council of the British Interplanetary Society since 1937 and is at present chairman of the society. He is also a member of the British Astronomical Society. He has published numerous papers on rockets, electronics, and astronomy.

R. J. GAUTHERET,
D.Sc.,

Was born in 1910 and studied at the Faculty of Science in the University of Paris under direction of Professor Guilliermond. He was appointed Professor of Plant Biology at the Sorbonne in 1942. His researches are chiefly concerned with plant tissue culture, a subject in which he was one of the first to achieve success. He founded the earliest laboratory entirely devoted to this work and, with the aid of his collaborators, aims at applying the new technique to the solution of various problems of morphology, physiology, and pathology. Professor Gautheret has fully described his results in two general works, published in Paris. He has also published papers on cell physiology, particularly on the vital coloration of plant cells.

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